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AFRPL-TR-67-274

(Unclassified Title)

ENGINEERING PROPERTY DATA ON ROCKET PROPELLANTS

Fifth Quarterly Report

Rocketdyne
A Division of North American Rockwell Corporation
6633 Canoga Avenue
Canoga Park, California

October 1967

AD 385671

> Group 4
> Downgraded at 3-Year Intervals
> Declassified After 12 Years

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Air Force Rocket Propulsion Laboratory
Research and Technology Division
Edwards Air Force Base, California
Air Force Systems Command
United States Air Force

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An order of secrecy having been issued in the above-entitled application by the Commissioner of Patents, the principals as designated in said order are authorized to disclose the subject matter to any person of the classes hereinafter specified if such person is known to the principal disclosing to be concerned directly in an official capacity with the subject matter, providing that all reasonable safeguards are taken to otherwise protect the invention from unauthorized disclosure. The specified classes are:--

(a) Any officer or employee of any department, independent agency or bureau of the Government of the United States.

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The provisions of this permit do not in any way lessen responsibility for the security of the subject matter as imposed by any Government contract of the provisions of the existing laws relating to espionage and national security.

First Assistant Commissioner

AFRPL-TR-67-274

(Unclassified Title)

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Air Force Rocket Propulsion Laboratory
Research and Technology Division
Edwards Air Force Base, California
Air Force Systems Command
United States Air Force

FOREWORD

(U) This is a quarterly technical report submitted in compliance with
Contract AF04(611)-11407. The research reported herein, which covers
the period 1 July through 30 September 1967, was sponsored by the Air Force
Rocket Propulsion Laboratory, Research and Technology Division, Air Force
Systems Command, United States Air Force, Edwards, California, with
Mr. G. Allen Beale acting as the Air Force Project Officer..

(U) This program was conducted in the Chemical and Material Sciences
Department of the Rocketdyne Research Division, with Dr. E. F. C. Cain
serving as Program Manager and Mr. M. T. Constantine serving as the Re-
sponsible Project Scientist. Other technical personnel who have contri-
buted to this effort include K. J. Youel (Phases I and III), Dr. J. F. Hon
(Phase II), Dr. W. Unterberg (Phase II), Dr. S. E. Rodriguez (Phase II),
J. V. Lecce (Phase II), R. W. Melvold (Phase II), and J. Quaglino (Phase II).

(U) This report has been assigned the Rocketdyne identification number
R-6638-5.

(U) Publication of this report does not constitute Air Force approval of
the report's findings or conclusions. It is published only for the ex-
change and stimulation of ideas.

W. H. Ebelke, Colonel, USAF
Chief, Propellant Division

ABSTRACT

(U) The results of the sixth quarter year's effort of a 24-month program on the analytical and experimental characterization of the physical properties of selected liquid propellants are presented in three phases. In Phase I, a continuous review of the literature was conducted to ensure the acquisition and documentation of the latest possible propellant properties data for evaluation and possible inclusion into a propellant properties handbook. Phase II experimental efforts have resulted in additional measurements of chlorine trifluoride pressure–volume–temperature relationships in the critical region and the establishment of vapor pressure equations. Sonic velocity measurements were conducted in chlorine trifluoride and chlorine pentafluoride under pressurized conditions, and in saturated liquid nitrogen tetroxide and MHF-3. Nitrogen gas solubility was determined in chlorine pentafluoride and the viscosity of chlorine pentafluoride was measured at high pressures. The specific heats of MHF-3 and MHF-5 were measured. Phase III efforts included the evaluation and assembly of all data generated in Phases I and II and the compilation of surface tension data on chlorine trifluoride, chlorine pentafluoride, nitrogen tetroxide, 50 N_2H_4-50$(CH_3)_2N_2H_2$ fuel blend, hydrazine, MMH, UDMH, MHF-3, and MHF-5.

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INTRODUCTION

(U) Under Contract AF04(611)-10546, Rocketdyne completed a 12-month analytical and experimental program (Ref. 1) on the rational and systematic physical characterization of selected liquid rocket propellants. The overall objective of this program, which was conceived as an initial step toward elimination of propellant data gaps, was to assemble and experimentally complete the data on essential physical properties of current and near-term liquid rocket propellants over temperature and pressure ranges of practical use to propulsion engineering. During this program, experimental efforts resulted in measurement of: (1) chlorine trifluoride (ClF_3) phase properties (including critical temperature); (2) IRFNA and chlorine pentafluoride (ClF_5) sonic velocities (and calculation of compressibilities); (3) ClF_3 and $CH_3N_2H_3$ specific heats (and correction of previously determined ClF_5 specific heat data); (4) thermal conductivities of the 50 N_2H_4 - 50 $(CH_3)_2N_2H_2$ fuel blend and $CH_3N_2H_3$; and (5) the design and preliminary assembly of apparatuses for measurement of inert-gas solubility in liquids and liquid viscosities at extended temperatures and pressures. Analytical efforts, initiated with an extensive literature survey, included the assembly and evaluation of physical property data on MIF-1, MHF-3, MHF-5, ClF_3, and ClF_5 for future correlation and summary publication.

(U) The present three-phase program being conducted under Contract AF04(611)-11407, represents a 24-month extension and expansion of the objectives of the previous effort. Phase I effort consists of a continuous review of the current literature to document reported propellant properties. In Phase II, effort is directed at the experimental determination of unavailable engineering data, for selected oxidizers and fuels, which are required to design rocket engine hardware. Effort under Phase III includes the compilation, correlation, and evaluation of all data obtained from Phases I and II and presentation of the valid data in an annual technical report.

(U) During the first 15 months of the current program, which has been reported in an Annual Summary Report (Ref. 2) and in a subsequent Quarterly

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Report (Ref. 3), the continuous documentation of current propellant properties data was maintained with a detailed review of 579 reports and of all current releases of the standard abstract sources. Experimental efforts in this 15-month period resulted in measurements of: (1) ClF_3 density and vapor pressure over a wide temperature range (with a corresponding estimation of critical properties); (2) saturated and pressurized liquid ClF_5 and ClF_3 sonic velocities (and calculation of adiabatic compressibilities); (3) $N_{2(g)}$ solubility in ClF_5, (4) UDMH, 50 N_2H_4-50 $(CH_3)_2N_2H_2$, ClF_3, and MHF-3 specific heats; (5) thermal conductivities of UDMH, MHF-3, and MHF-5; and (6) ClF_5 viscosity. Phase III analytical efforts resulted in correlation of Phase II experimental data; the preparation of complete physical property bibliographies on B_2H_6 and N_2H_4 and the initiation of N_2O_4 and MMH physical property bibliographies; the publication of N_2H_4 physical property data sheets; a curve fit of specific heat data on solid ClF_3; and a report of unpublished data on ClF_5 boiling point and ClF_5 storability.

(U) Progress achieved in a continuation of these objectives and efforts during the sixth quarter year of the current program is summarized in this report.

SUMMARY

(U) Analytical and experimental research conducted during the sixth quarter year of a current 24-month program to complete the data on essential physical properties of current and near-term liquid propellants of interest to the Air Force is described in three phases.

(U) In Phase 1, a continuous survey of the current propellant literature has resulted in the preliminary screening of 1995 reports acquired and cataloged by Rocketdyne during this period; 162 of these reports were reviewed in detail for pertinent engineering properties data on liquid propellants.

(U) The experimental characterization of essential physical properties of selected propellants was conducted under Phase II. During the current report period, these efforts were directed at measurements of: ClF_3 phase properties in the critical region; sonic velocity in ClF_5 and ClF_3 under pressurized conditions; sonic velocity in saturated liquid N_2O_4 and MHF-3; gaseous nitrogen solubility in ClF_5; specific heat of MHF-3 and MHF-5; and ClF_5 viscosity.

(U) A constant-volume vapor pressure apparatus was used to extend the available experimental data on ClF_3 phase properties. As a result of the current experimental data, the vapor pressure of ClF_3 was correlated from -30 to 179 C (-22 to 394 F) with the following equations:

$$\log P_{(atm)} = 4.5064 - \frac{1101.65}{t_{(C)} + 233.0}$$

and

$$\log P_{(psia)} = 5.6733 - \frac{1982.97}{t_{(F)} + 387.4}$$

(U) Data resulting from measurements of sonic velocity in ClF_5 and ClF_3 under total pressurizations of 500 and 1000 psia were correlated and curve fit with the following equations:

500 psia

ClF_5: $c_{(m/sec)} = 1696 - 3.642\ T_{(K)}$

and

$c_{(ft/sec)} = 5564.3 - 6.637\ T_{(R)}$

ClF_3: $c_{(m/sec)} = 2007 - 3.878\ T_{(K)}$

and

$c_{(ft/sec)} = 6584.6 - 7.067\ T_{(R)}$

1000 psia

ClF_5: $c_{(m/sec)} = 1670 - 3.487\ T_{(K)}$

and

$c_{(ft/sec)} = 5479.0 - 6.355\ T_{(R)}$

ClF_3: $c_{(m/sec)} = 2008 - 3.847\ T_{(K)}$

and

$c_{(ft/sec)} = 6587.9 - 6.995\ T_{(R)}$

(U) Results from experimental determinations of sonic velocity in saturated liquid N_2O_4 over a temperature range of -5 to 56 C (23 to 132 F) were curve fit with the following equations.

$$c_{(m/sec)} = 2296 - 4.425\ T_{(K)}$$

and

$$c_{(ft/sec)} = 3825 - 8.065\ t_{(F)}$$

Adiabatic compressibilities calculated from these sonic velocity data and corresponding temperature-N_2O_4 density data established the following relationships:

$$\beta_{s(atm^{-1})} = 5.776 \times 10^{-5} + 5.454 \times 10^{-7}\ t_{(C)} + 5.185 \times 10^{-9}\ t_{(C)}^2$$

$$- 1.659 \times 10^{-11}\ t_{(C)}^3 + 5.291 \times 10^{-13}\ t_{(C)}^4$$

and

$$\beta_{s(psi^{-1})} = 3.394 \times 10^{-6} + 1.260 \times 10^{-8}\ t_{(F)} + 1.486 \times 10^{-1}\ t_{(F)}^2$$

$$- 6.329 \times 10^{-13} t_{(F)}^3 + 3.431 \times 10^{-13}\ t_{(F)}^4$$

(C) Preliminary measurements of sonic velocity in MHF-3 resulted in a value of 1604 m/sec (5262 ft/sec) ±4 percent at 25 C (77 F).

(U) Measurements of gaseous nitrogen solubility in liquid ClF_5 were extended to higher temperature and pressure levels. As a result, the following expressions have been derived for total solubility (S, lb N_2/lb ClF_5) as a function of pressure (P, psia) at temperatures of 90, 120, 150, and 180 F, respectively:

$$S = 1.62 \times 10^{-5}\ (P-72) + 0.36 \times 10^{-8}\ (P-72)^2$$

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$$S = 1.97 \times 10^{-5} (P-115) + 0.33 \times 10^{-8} (P-115)^2$$

$$S = 2.30 \times 10^{-5} (P-176) + 0.31 \times 10^{-8} (P-176)^2$$

$$S = 2.80 \times 10^{-5} (P-257)$$

(C) Specific heat measurements on liquid MHF-3 were completed over the temperature range of -46.0 to 47.3 C (-50.8 to 117.2 F) through the use of an adiabatic calorimeter. A curve fit of the experimental data resulted in the following equations:

$$C_{p(cal/gm-C)} = 0.708 + 3.807 \times 10^{-4} t_{(C)} + 2.110 \times 10^{-6} t_{(C)}^2$$

and

$$C_{p(Btu/lb-F)} = 0.702 + 1.698 \times 10^{-4} t_{(F)} + 6.512 \times 10^{-7} t_{(F)}^2$$

(C) Experimental specific heat data obtained on liquid MHF-5 over a temperature range of -47.4 to 7.5 C (-53.3 to 45.5 F) in this program were correlated with other available MHF-5 specific heat data at higher temperatures. This correlation resulted in the following MHF-5 specific heat-temperature relationships over a temperature range of -47.4 to 68.0 C (-53.3 to 154.4 F):

$$C_{p(cal/gm-C)} = 0.664 + 1.21 \times 10^{-4} t_{(C)}$$

and

$$C_{p(Btu/lb-F)} = 0.662 + 6.74 \times 10^{-5} t_{(F)}$$

(U) The applicability of the present steady-state, concentric-cylinder conductivity cell to oxidizer thermal conductivity measurements is currently being evaluated. Upon assurance of a suitable and compatible apparatus and technique, thermal conductivity measurements will be initiated on ClF_5.

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(U) Liquid ClF_5 viscosity measurements at 202 F in a stainless-steel capillary viscometer over a total pressure range of 360 to 910 psia indicated that these pressures have no significant effect on the ClF_5 kinematic viscosity. The absolute viscosity of the saturated liquid at this temperature is 0.168 centipoise.

(U) Efforts under the Phase III review and evaluation of the data generated under Phases I and II were directed at the continuation of the assembly of engineering property bibliographies and physical property data sheets on N_2O_4. To support specific Phase II requirements, experimental N_2O_4 density data were assembled and correlated over a temperature range of -11.2 to 93.3 C (11.8 to 199.9 F). In addition, all published surface tension data on ClF_3, ClF_5, N_2O_4, 50 N_2H_4-50 UDMH, N_2H_4, MMH, UDMH, MHF-3, and MHF-5 were compiled and summarized.

PHASE I: LITERATURE SEARCH

OBJECTIVE

(U) The Phase I objective is the maintenance of a continuous review of the current literature and efforts of other investigators in the field to ensure acquisition and documentation of the latest possible propellant properties data for evaluation and possible inclusion into a propellant properties hand-book. This survey is designed to include, but not to be necessarily limited to, the properties of the following fuels and oxidizers:

Oxidizers	Fuels
Liquid Oxygen (LO_2)	Liquid Hydrogen (LH_2)
Chlorine Pentafluoride (ClF_5)	50 N_2H_4-50 $(CH_3)_2N_2H_2$ Fuel Blend
Chlorine Trifluoride (ClF_3)	Hydrazine (N_2H_4)
Fluorine (F_2)	MMH $(CH_3N_2H_3)$
Hydrogen Peroxide (H_2O_2)	UDMH $\left[(CH_3)_2N_2H_2\right]$
Nitrogen Tetroxide (N_2O_4)	N_2H_4-MMH Mixtures
Mixed Oxides of Nitrogen $(N_2O_4$-NO)	Hybaline B-3
FLOX Mixtures $(LF_2$-$LO_2)$	Alumizine
Oxygen Difluoride (OF_2)	Pentaborane (B_5H_9)
Tetrafluorohydrazine (N_2F_4)	Diborane (B_2H_6)
	MHF Blends
	MAF Blends

RESULTS AND ACCOMPLISHMENTS

(U) A formal survey of current propellant literature, initiated under Contract AF04(611)-10546 (Ref. 1), is being continued as Phase I of the present program. This survey, which includes the location, acquisition,

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and documentation of all available propellant properties data of interest
to the Air Force, was originally directed at a comprehensive review of
physical properties data. However, under the present contract, the survey
has been expanded to include additional engineering properties data.

(U) This survey is being maintained through two primary techniques. The
main portion of the effort is directed at the survey of all reports acquired
by Rocketdyne; these include reports obtained as a result of individual per-
sonnel requests as well as those acquired through normal distribution channels.
Each of these reports is surveyed with respect to subject matter, and re-
ports containing potential propellant properties data are selected for de-
tailed review. All pertinent data contained in these reports are documented
for assembly under Phase III.

(U) To aid in the complete awareness of all available propellant properties
data and their subsequent acquisition and documentation, this report survey
effort is supplemented by a continuous survey of the current releases of
Chemical Abstracts, NASA CSTAR Abstracts, CPIA Chemical Propulsion Abstracts,
Defense Documentation Center (DDC) Technical Abstract Bulletin (TAB), NBS
Cryogenic Data Center Current Awareness Service, and propellant manufac-
turers' bulletins. Any pertinent reports located through these sources that
have not been acquired previously by Rocketdyne are ordered and reviewed in
detail.

(U) During the current report period, 1995 reports were surveyed; of this
total, 162 reports were reviewed in detail for propellant properties data.
This current review included report bibliographies on $CH_3N_2H_3$ and N_2O_4,
which were obtained (by Rocketdyne request) from the Defense Documentation
Center. The pertinent data abstracted from these reports are being com-
piled and evaluated under Phase III.

PHASE II: EXPERIMENTAL DETERMINATIONS

OBJECTIVE

(U) Phase II is designed for the experimental characterization of essential physical properties of selected liquid propellants. This phase essentially constitutes a 24-month continuation of the efforts initiated under Phase II of Contract AF04(611)-10546 (Ref. 1). Selection of the propellants and properties to be characterized experimentally is related to the unavailability of required data and relative importance of the data to the Air Force. Initial efforts have emphasized the completion of those propellant properties recommended for initial characterization under the previous program. Additional efforts are continuing in an order related to the importance of the data to the Air Force as determined by the Air Force Project Engineer.

(U) The selected properties are being determined over the liquidus temperature range and over a pressure range of 14.7 to 1000 psi, where practical. Changes to the selected list can be made at any time during the program through mutual agreement of Rocketdyne and the Air Force Contracting Officer. Standard test methods are being used when available. Unique or new test methods to be used must be approved by the Air Force Contracting Officer.

RESULTS AND ACCOMPLISHMENTS

(U) Phase II efforts during the current period were directed at:

1. Continued characterization of ClF_3 phase properties in the high-temperature and critical region

2. Experimental measurement of sonic velocity in saturated N_2O_4 and MHF-3 and correlation of previously obtained data on sonic velocity in ClF_5 and ClF_3 at pressures above saturation

3. Continuation of $N_{2(g)}$ solubility measurements in ClF_5

4. Completion of MHF-3 and MHF-5 specific heat measurements

5. Initiation of thermal conductivity measurements on selected oxidizers

6. Extension of the ClF_5 viscosity measurements

The efforts conducted under each of these tasks are described in the following paragraphs.

Phase Property Measurements

(U) Current phase property measurements have been designed for the reliable extension of the available experimental data on ClF_3 into the critical range. Previous efforts (Ref. 2) in this program had expanded and correlated available density data (Ref. 1 and 4) on saturated liquid ClF_3 over a temperature range of -22 to 161 C (-8 to 322 F). Vapor pressure measurements (Ref. 2 and 3) on ClF_3 had been conducted over a temperature range of 25.65 to 148.58 C (78.17 to 299.4 F) to increase the reliability of previously available (Ref. 1 and 5) vapor pressure data in the high-temperature region. In addition, a ClF_3 critical temperature measurement (using the liquid-vapor meniscus disappearance technique) of 179.6 ±0.5 C (355.3 F) was reported (Ref. 1) and used (Ref. 3) with the preliminary vapor pressure data to calculate a critical pressure of 961 psia (65.4 atm) and a critical density of 0.88 gm/cc (54.9 lb/cu ft).

(U) The expansion of these phase property measurements in the critical region is being accomplished through the experimental determination of pressure-temperature relationships of known quantities of ClF_3 using a constant-volume vapor pressure apparatus (which has been described previously in Ref. 2). To ensure attainment of reliable data, the 0- to 1000-psia range pressure transducer used with the apparatus was calibrated with a Heise gage at temperatures and pressures over the intended ranges

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of use. Because the calibration results showed that the transducer output was significantly sensitive to temperature changes, a second-order function was required in both the output voltage and input temperature terms during data reduction. A curve fit of the calibration data with an appropriate equation was obtained using a least-squares computer program.

(U) Chlorine Trifluoride Vapor Pressure. During the present effort, additional pressure-temperature measurements (using variations of the amount of propellant-grade ClF_3 in the apparatus) were conducted in the constant-volume, vapor-pressure apparatus over a temperature range of 4.20 to 146.60 C (39.56 to 295.88 F). The resulting vapor pressure data are given in Table 1. These data were combined with the previously reported values (Ref. 2, 3, and 5) and correlated with an Antoine equation using a least-squares computer program. The resulting curve fit (Fig. 1) gave the following equations over the temperature range of -30 to 179 C (-22 to 354 F):

$$\log P_{(atm)} = 4.5064 - \frac{1101.65}{t_{(C)} + 233.0}$$

and

$$\log P_{(psia)} = 5.6733 - \frac{1982.97}{t_{(F)} + 387.4}$$

The large (5 percent) standard deviation of these curve fits is somewhat reasonable for a 3-constant equation over the large-temperature range; however, additional measurements are indicated. Using these vapor pressure equations and the experimental critical temperature of 179.6 C (355.3 F), a critical pressure of 68.6 atm (1008 psia) can be calculated.

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TABLE 1

CHLORINE TRIFLUORIDE VAPOR PRESSURE DATA

Sample No.	Temperature		Vapor Pressure, psia
	C	F	
1	40.08	104.14	48.5
1	66.80	152.24	108.1
1	96.00	204.80	220.6
2	39.28	102.70	44.9
2	61.83	143.29	89.9
2	78.58	173.44	141.7
2	101.08	213.94	226.4
3	4.20	39.56	11.0
3	45.43	113.77	56.3
3	61.43	142.57	92.3
3	75.78	168.40	136.2
3	93.28	199.90	207.7
3	122.30	252.14	381.6
3	146.60	295.88	595.7

CURVE FIT FROM -32 TO 354 F WITH EQUATION:

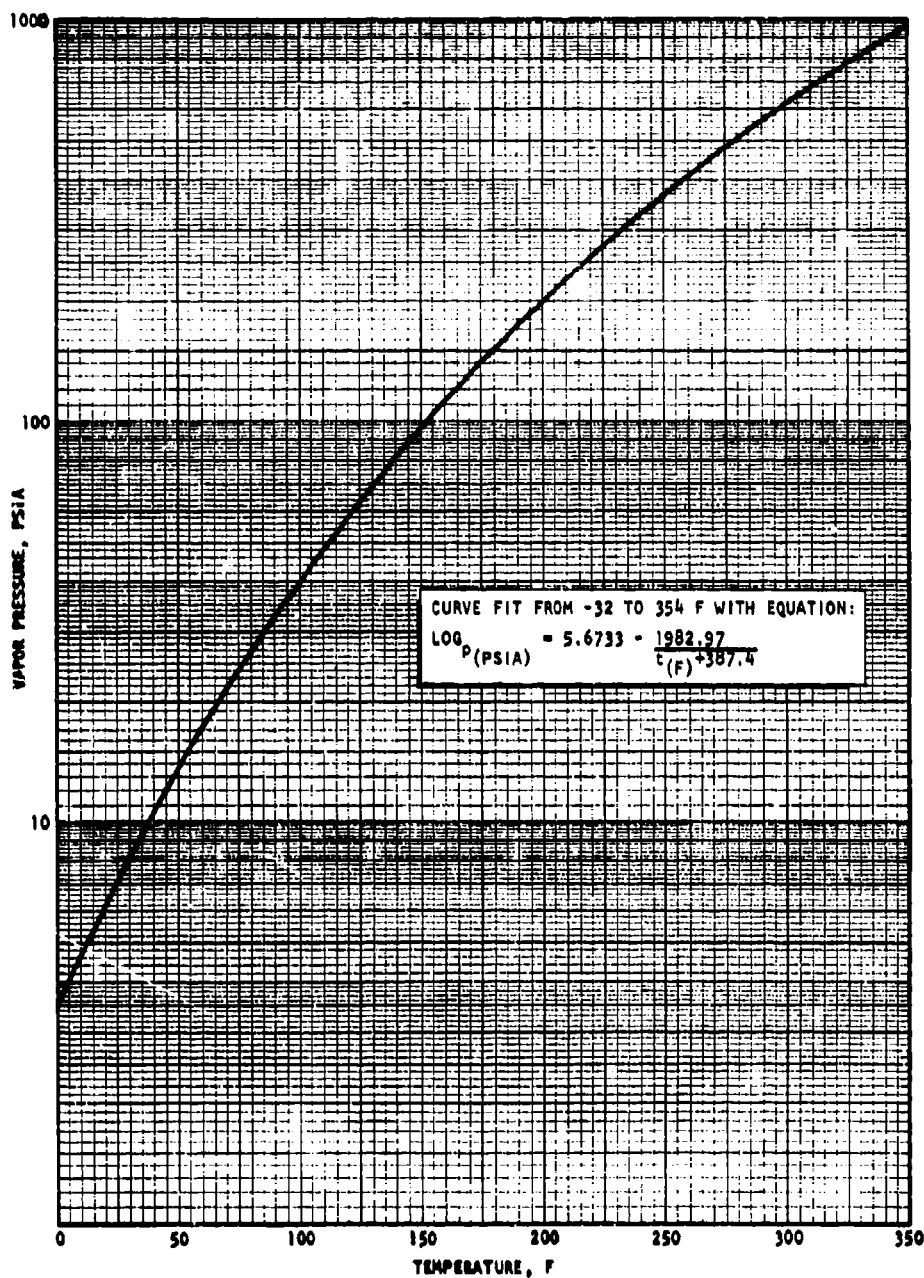$$\text{LOG}_{P(PSIA)} = 5.6733 - \frac{1982.97}{t_{(F)}+387.4}$$

Figure 1. Vapor Pressure of Chlorine Trifluoride

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Sonic Velocity (and Compressibility) Measurements

(U) Determinations of sonic velocity and adiabatic compressibility of ClF_5, ClF_3, and N_2O_4 have been conducted with an apparatus described in Ref. 2. A similar apparatus (Fig. 2) is being used for sonic velocity measurements in MHF-3. With these apparatuses, the velocity of sound in a liquid is obtained experimentally by measuring the time required for an ultrasonic acoustic wave to travel a known distance in the test liquid. Using the resulting velocity of sound (c) and the density (ρ) of the liquid at the corresponding temperature, the adiabatic compressibility (β_s) of the liquid is calculated from the relationship:

$$\beta_s = \frac{1}{\rho c^2}$$

(U) **Sonic Velocity in Chlorine Pentafluoride.** The data from previous measurements (Ref. 3) of sonic velocity in ClF_5 under pressurized (with GN_2) liquid conditions were curve fit using a least-squares computer program. The resulting equations with their standard deviation (σ) are as follows:

500-psia total pressure, -15 to 69 C (5 to 156.2 F)

$$c_{(m/sec)} = 1696 - 3.642\ T_{(K)} \qquad (\sigma = \pm 0.7\ m/sec)$$

and

$$c_{(ft/sec)} = 5564.3 - 6.637\ T_{(R)} \qquad (\sigma = \pm 2.3\ ft/sec)$$

1000-psia total pressure, -15 to 46 C (5.0 to 114.8 F)

$$c_{(m/sec)} = 1670 - 3.487\ T_{(K)} \qquad (\sigma = \pm 1.6\ m/sec)$$

and

$$c_{(ft/sec)} = 5479.0 - 6.355\ T_{(R)} \qquad (\sigma = \pm 5.2\ ft/sec)$$

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TEFLON
O-RING

ULTRASONIC
TRANSDUCER

TEST
FLUID

SONIC VELOCITY CELL

RADIO
FREQUENCY

REFLECTOSCOPE   OSCILLOSCOPE
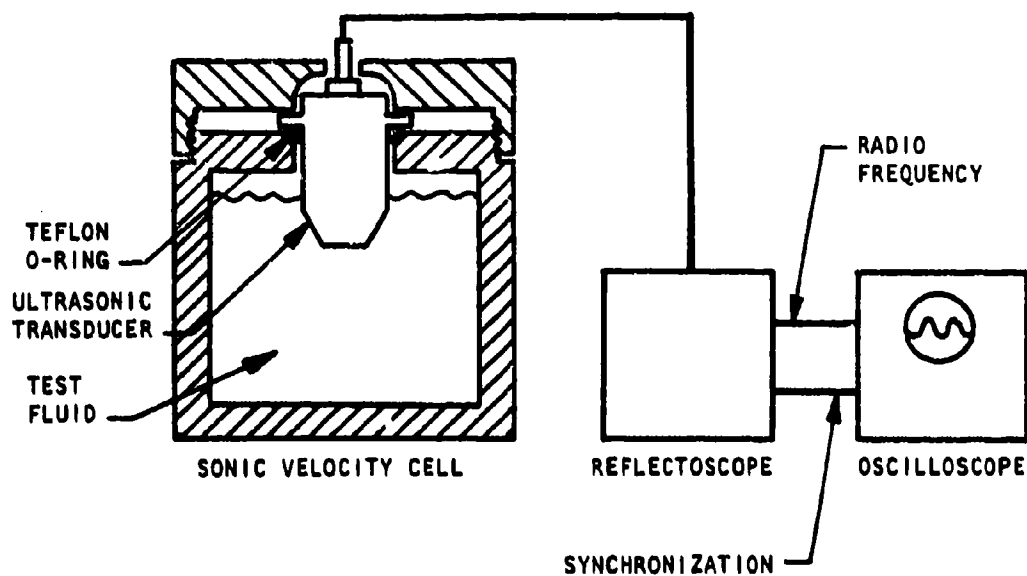
SYNCHRONIZATION

Figure 2.   Sonic Velocity Apparatus

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The curve fits expressed in the metric units are graphically illustrated in Fig. 3 and compared with previously established (Ref. 2) data for the saturated liquid.

(U) Sonic Velocity in Chlorine Trifluoride. During this report period, sonic measurements were completed in liquid ClF_3 under total pressurizations (with gaseous nitrogen) of 500, 800, and 1000 psia using the experimental procedure previously described in Ref. 3. The resulting data are shown in Table 2 with the previously established (Ref. 2) saturated liquid data. The data from the measurements at 500 and 1000 psia were curve fit (through a least-squares computer program) with the following equations:

500-psia total pressure, -14 to 75 C (6.8 to 167.0 F)

$$c_{(m/sec)} = 2007 - 3.878 \ T_{(K)} \qquad (\sigma = \pm 2.2 \ m/sec)$$

and

$$c_{(ft/sec)} = 6584.6 - 7.067 \ T_{(R)} \qquad (\sigma = \pm 7.2 \ ft/sec)$$

1000-psia total pressure, -14 to 56 C (6.8 to 132.8 F)

$$c_{(m/sec)} = 2008 - 3.837 \ T_{(K)} \qquad (\sigma = \pm 1.5 \ m/sec)$$

and

$$c_{(ft/sec)} = 6587.9 - 6.995 \ T_{(R)} \qquad (\sigma = \pm 4.9 \ ft/sec)$$

Plots of these and the saturated liquid data curve fits are illustrated (in metric units) in Fig. 3.

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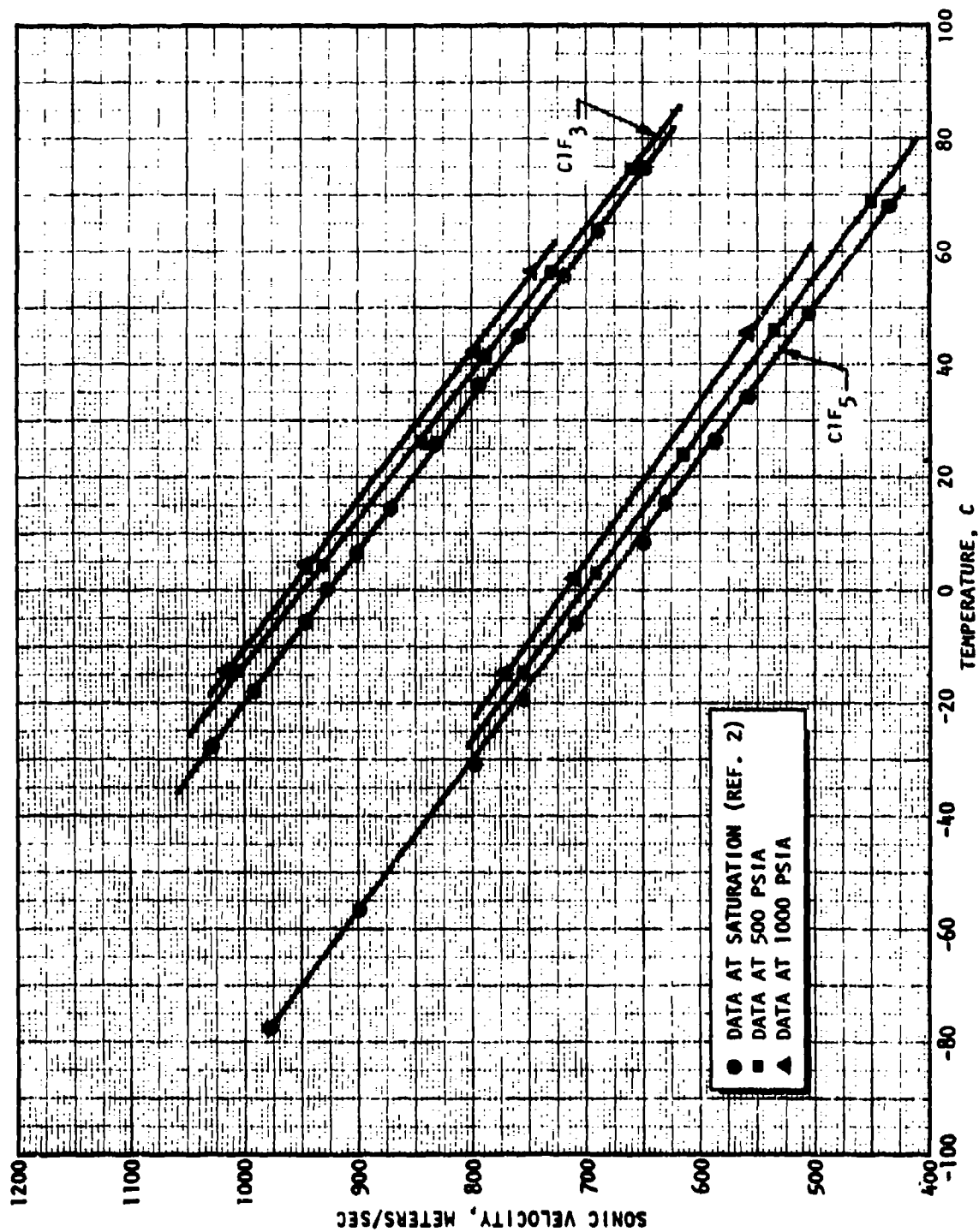
Figure 3. Sonic Velocity in ClF_3 and ClF_5

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TABLE 2

VELOCITY OF SOUND IN SATURATED
LIQUID CHLORINE TRIFLUORIDE

Temperature		Total Pressure, psia	Sonic Velocity	
C	F		m/sec	ft/sec
-14.12	6.6	Saturation*	991.9	3254.3
		500	1002.6	3289.4
		800	1010.0	3313.6
		1000	1013.5	3325.1
4.43	40.0	Saturation*	923.1	3028.5
		500	933.5	3062.7
		800	939.2	3081.4
		1000	945.1	3100.7
41.68	107.02	Saturation*	770.9	2528.5
		500	784.1	2571.8
		800	793.1	2601.4
		1000	798.4	2618.7
56.23	133.21	Saturation*	716.3	2349.5
		500	729.8	2393.7
		800	739.2	2424.6
		1000	745.5	2445.2
74.90	166.82	500	659.1	2161.8

* Previously established in Ref. 2

(U) _Sonic Velocity in Nitrogen Tetroxide_. The velocity of sound was measured in saturated liquid N_2O_4 (propellant-grade) over a temperature range of -5 to 56 C (23 to 132 F). The resulting values (Table 3 and Fig. 4) were curve fit using a least-squares computer program. The resulting equations, in both metric and English units, are as follows:

$$c_{(m/sec)} = 2296 - 4.425\ T_{(K)} \qquad (\sigma = \pm3\ m/sec)$$

and

$$c_{(ft/sec)} = 3825 - 8.065\ t_{(F)} \qquad (\sigma = \pm10\ ft/sec)$$

(U) _Adiabatic Compressibility of Nitrogen Tetroxide_. The N_2O_4 sonic velocity data were used with saturated liquid N_2O_4 density data (noted in Phase III) to calculate the adiabatic compressibility (β_s) of N_2O_4. The equations resulting from curve fits of the calculated data are as follows:

$$\beta_{s(atm^{-1})} = 5.776 \times 10^{-5} + 5.454 \times 10^{-7} t_{(C)} + 5.185 \times 10^{-9} t_{(C)}^2$$

$$- 1.659 \times 10^{-11} t_{(C)}^3 + 5.291 \times 10^{-13} t_{(C)}^4$$

and

$$\beta_{s(psi^{-1})} = 3.394 \times 10^{-6} + 1.260 \times 10^{-8} t_{(F)} + 1.486 \times 10^{-10} t_{(F)}^2$$

$$- 6.329 \times 10^{-13} t_{(F)}^3 + 3.431 \times 10^{-15} t_{(F)}^4$$

The standard deviations of these curve fits are $\pm5.0 \times 10^{-8}$ atm^{-1} and $\pm3.6 \times 10^{-9}$ psi^{-1}, respectively. An illustration of a plot of the expression in metric units is shown in Fig. 5.

(C) _Sonic Velocity in MHF-3_. Measurements of the velocity of sound in MHF-3 (nominal composition of 86 w/o $CH_3N_2H_3$ - 14 w/o N_2H_4) are being

TABLE 3

VELOCITY OF SOUND IN SATURATED
LIQUID NITROGEN TETROXIDE

Temperature		Sonic Velocity	
C	F	m/sec	ft/sec
-5.33	22.41	1112	3648
-0.05	31.82	1086	3563
6.73	44.11	1063	3487
12.23	54.01	1027	3369
23.58	74.44	983	3225
25.48	77.86	975	3198
36.58	97.84	926	3038
40.88	105.58	905	2969
48.10	118.58	872	2861
56.10	132.98	842	2762

CURVE FIT FROM -5 TO 56C WITH EQUATION:

$c_{(m/sec)} = 2296 - 4.425T_{(K)}$
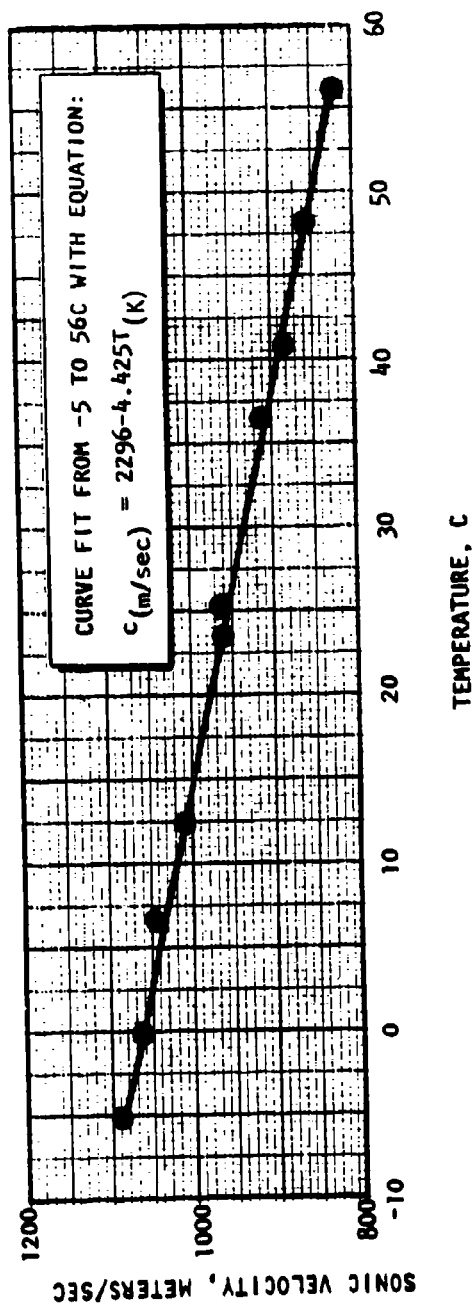
SONIC VELOCITY, METERS/SEC

TEMPERATURE, C

Figure 4. Velocity of Sound in Saturated Liquid Nitrogen Tetroxide

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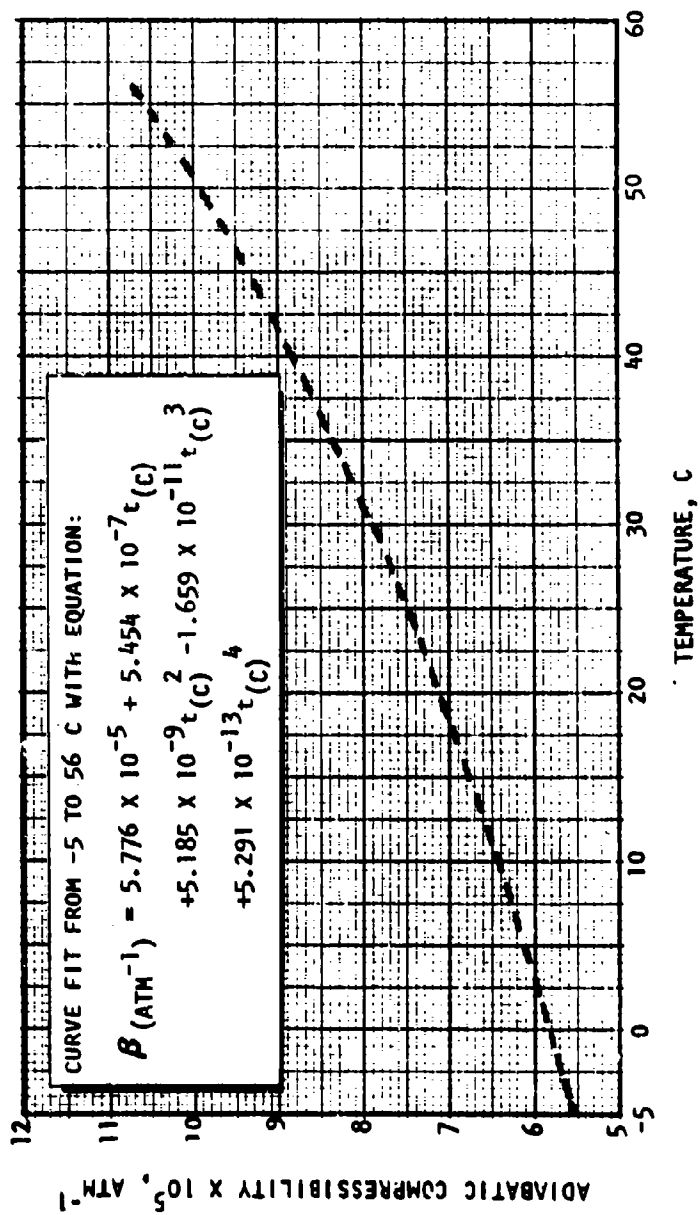
Figure 5. Adiabatic Compressibility of Saturated Liquid Nitrogen Tetroxide

conducted in the apparatus illustrated in Fig. 2. However, initial testing indicated that the epoxy coating which covered the ultrasonic transducer crystal (Automation Industries No. 57A 2946) used in the existing system was incompatible with MHF-3. A new transducer with a Kel-F protective cover for the ceramic crystal has been ordered.

(C) During the interim, a preliminary sonic velocity of 1604 m/sec (5262 ft/sec) ±4 percent was measured in a MHF-3 sample at 25 C (77 F). This measurement was accomplished by protecting the incompatible epoxy coating with Halocarbon Wax No. 10. At the end of this run, the normally colorless MHF-3 sample had a brownish color which indicated some degree of decomposition and/or reaction. Thus, additional measurements in MHF-3 will be temporarily discontinued until receipt of the new transducer.

Inert-Gas Solubility Measurements

(U) The apparatus for measuring inert-gas solubility in liquid propellants was previously described in detail in Ref. 2. Through the use of this apparatus and the attendant operating procedure, the differential solubility (i.e., the mass of gas dissolved per unit mass of propellant per unit pressure increase) of the gas in the liquid is measured at a particular temperature and pressure. From these data, the total solubility at a particular total pressure can be obtained by the integration of this differential solubility (with respect to pressure) between the propellant vapor pressure (lower limit) and the total pressure (upper limit).

(U) The experimental procedure generally involves the introduction of a known quantity of inert gas into a partly filled propellant cell of known volume. The resulting pressure rise is measured by means of a differential-pressure transducer both before and after the process of solution. These two data serve to establish the distribution of input gas between the ullage and the propellant.

(U) In the original experimental method, the two processes of equilibration (with and without solution) were carried out in succession after a gas input. Since the pressure increments were small, this procedure provided a close approximation to a differential process. However, difficulties in achieving vapor equilibrium within the ullage led to a modification in procedure. The modification (as described in Ref. 3) involved the observation of the two pressure equilibria separately over a sequence of gas inputs. The differential solubilities thus derived are averages over a significant pressure range. This modification has resulted in data of apparently greater reliability, but at a considerable cost in experimental and interpretative effort.

(U) Nitrogen Gas Solubility in Chlorine Pentafluoride. Previous efforts in this program (Ref. 3) had resulted in the measurements of nitrogen gas solubility in ClF_5 at three temperatures and pressures. During this quarter, these measurements were extended to a higher temperature and different pressures. The results of all of these measurements are summarized in Table 4. (It should be noted that some of the data previously reported in Ref. 3 have been revised and corrected as a result of the additional measurements.) The estimated accuracy of these data is ±5 percent; a major source of error in this approach arises from taking a small difference between two relatively large, experimentally measured quantities.

(U) These differential solubility data are plotted in Fig. 6 as a function of pressure increase (i.e., the difference between total pressure and the ClF_5 vapor pressure at the temperature noted). This difference is the range of integration used in determination of a total solubility. An average value of total pressure for the range shown in Table 4 was assigned to each point.

(U) A linear curve fit of the data shown in Fig. 6 resulted in the following equations:

$$(90\ F)\ \Delta S_{(lb\ N_2/lb\ ClF_5-psi)} = 1.62 \times 10^{-5} + 0.71 \times 10^{-8} \left[P_{(psia)}-72\right]$$

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TABLE 4

NITROGEN GAS SOLUBILITY IN CHLORINE PENTAFLUORIDE

Temperature, F	Vapor Pressure, psia	Total Pressure Range, psia	Differential Solubility, lb N_2/lb ClF_5-psi
90	72	430 to 470*	1.89×10^{-5}
		600 to 660	2.02×10^{-5}
		880 to 920	2.21×10^{-5}
120	115	580 to 610*	2.29×10^{-5}
		780 to 840	2.43×10^{-5}
150	176	460 to 510	2.50×10^{-5}
		600 to 650	2.56×10^{-5}
		740 to 770*	2.67×10^{-5}
180	257	380 to 450	2.83×10^{-5}
		670 to 720	2.71×10^{-5}
		840 to 880	2.85×10^{-5}

*Data at these conditions were previously reported in Ref. 3; revisions and corrections to these data have been made on the basis of the additional determinations.
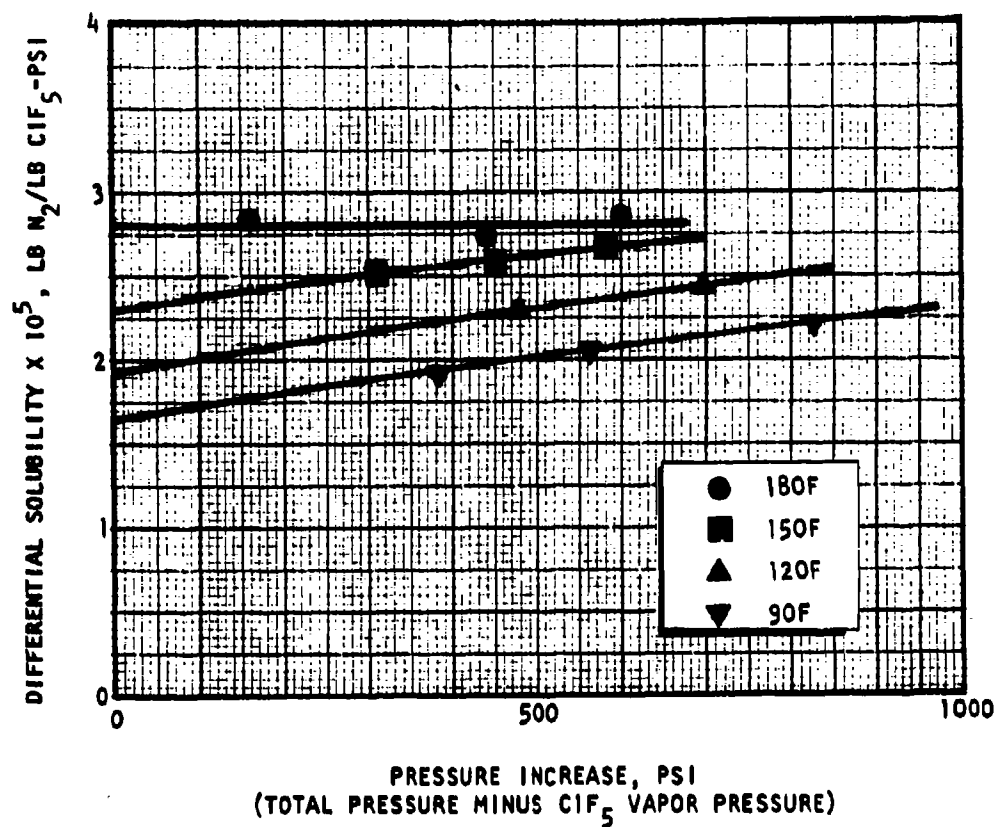
Figure 6. Differential Solubility of Gaseous
Nitrogen in Chlorine Pentafluoride

$$(120\ F)\quad \Delta S_{(lb\ N_2/lb\ ClF_5\text{-psi})} = 1.97 \times 10^{-5} + 0.65 \times 10^{-8}\left[P_{(psia)} - 115\right]$$

$$(150\ F)\quad \Delta S_{(lb\ N_2/lb\ ClF_5\text{-psi})} = 2.30 \times 10^{-5} + 0.63 \times 10^{-8}\left[P_{(psia)} - 176\right]$$

$$(180\ F)\quad \Delta S_{(lb\ N_2/lb\ ClF_5\text{-psi})} = 2.80 \times 10^{-5}$$

(U) These equations have been written in terms of the pressure increase (i.e., total pressure minus ClF_5 vapor pressure). The linear curve fits for the lower three temperatures show significant slopes in close agreement. However, at 180 F there is a negligible variation in differential solubility with pressure (according to the least-square criterion). This abrupt change at 180 F could be due to special experimental errors in the higher temperature data, although a re-examination of the experimental results does not support this suspicion.

(U) A total solubility (mass ratio of gas to propellant) as a function of total pressure is obtained by integrating the differential solubility equations over the pressure range between the ClF_5 vapor pressure and the total pressure. These integrations result in the following equations:

$$(90\ F)\quad S_{(lb\ N_2/lb\ ClF_5)} = 1.62 \times 10^{-5}\left[P_{(psia)} - 72\right] + 0.36 \times 10^{-8}\left[P_{(psia)} - 72\right]^2$$

$$(120\ F)\quad S_{(lb\ N_2/lb\ ClF_5)} = 1.97 \times 10^{-5}\left[P_{(psia)} - 115\right] + 0.33 \times 10^{-8}\left[P_{(psia)} - 115\right]^2$$

$$(150\ F)\quad S_{(lb\ N_2/lb\ ClF_5)} = 2.30 \times 10^{-5}\left[P_{(psia)} - 176\right] + 0.31 \times 10^{-8}\left[P_{(psia)} - 176\right]^2$$

$$(180\ F)\quad S_{(lb\ N_2/lb\ ClF_5)} = 2.80 \times 10^{-5}\left[P_{(psia)} - 257\right]$$

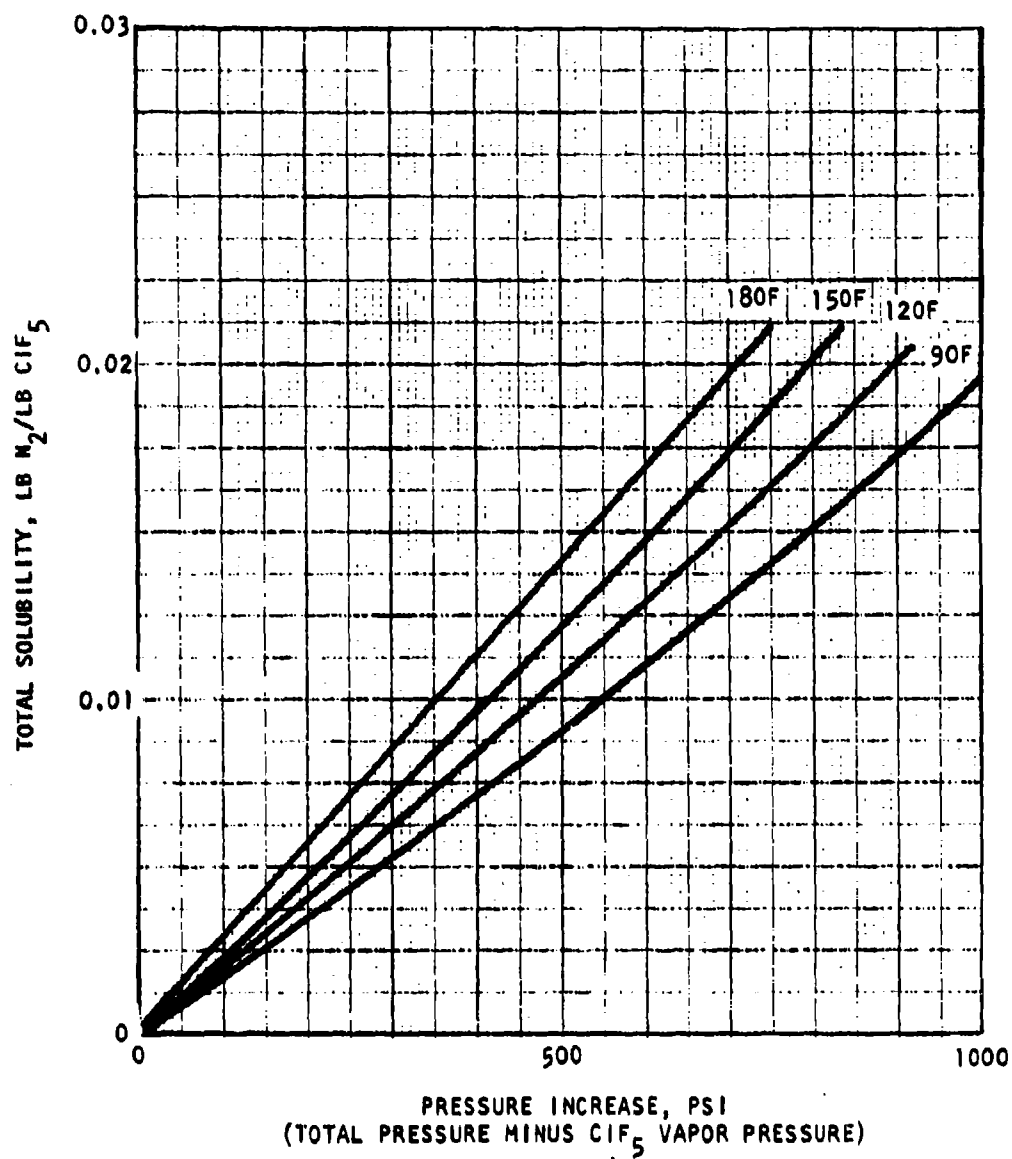The total solubilities given by these equations have been graphically illustrated in Fig. 7.

Figure 7.   Total Solubility of Gaseous Nitrogen in
             Chlorine Pentafluoride

Specific Heat Measurements

(U) During the current report period, efforts under the specific heat measurement task were directed at: (1) completion of specific heat measurements on the MHF-3 fuel blend, and (2) extension of the lower temperature limit of the MHF-5 fuel blend specific heat data. These experimental determinations were conducted in an adiabatic calorimeter, which has been previously described in Ref. 1, 3 and 6.

(C) Specific Heat of MHF-3

Specific heat measurements on the MHF-3 fuel blend (nominal composition of 86 w/o $CH_3N_2H_3$-14 w/o N_2H_4) were successfully completed on the liquid phase over the temperature range of -46.0 to 47.3 C (-50.8 to 117.2 F) using a calibrated sample container described in Ref. 3. The experimental specific heat data, which are listed in Table 5, are somewhat higher (e.g., ~2 percent greater at 20 C) than those data calculated from additive contributions of individual component specific heats. Through the use of a least-squares computer program, the data were curve fit over the given temperature range with the following equations:

$$C_{p(cal/gm-C)} = 0.708 + 3.807 \times 10^{-4}t_{(C)} + 2.110 \times 10^{-6}t_{(C)}^2$$

and

$$C_{p(Btu/lb-F)} = 0.702 + 1.698 \times 10^{-4}t_{(F)} + 6.512 \times 10^{-7}t_{(F)}^2$$

Figure 8 illustrates a graphical representation of the curve fit in the metric units. The average scatter of the experimental data from this smoothed specific heat-temperature curve is ±0.4 percent.

(U) Results of chemical analysis of the MHF-3 sample used in the specific heat measurements are also shown in Table 5.

TABLE 5

EXPERIMENTAL SPECIFIC HEAT OF MHF-3
FUEL BLEND*

| Temperature | | Specific Heat |
C	F	cal/gm-C
-46.01	-50.82	0.695
-44.48	-48.06	0.693
-43.96	-47.13	0.691
-39.90	-39.82	0.692
-38.33	-36.99	0.698
-37.86	-36.15	0.704
-36.32	-33.38	0.705
-29.74	-21.53	0.700
-25.37	-13.67	0.700
-17.82	-0.08	0.699
-15.83	3.51	0.698
-8.92	15.94	0.704
-6.95	19.49	0.709
0.32	32.58	0.705
1.85	35.33	0.709
2.30	36.14	0.712
3.83	38.89	0.707
11.46	52.06	0.719
13.41	56.14	0.715
18.98	66.16	0.712
20.96	69.73	0.721
25.43	77.77	0.713
27.36	81.25	0.721
32.64	90.75	0.723
34.58	94.22	0.724
40.60	105.08	0.724
42.52	108.65	0.737
44.76	112.57	0.730
47.31	117.16	0.727

*Sample Composition:

$CH_3N_2H_3$, w/o	84.7
N_2H_4, w/o	14.0
H_2O, w/o	1.0
NH_3, w/o	0.1
CH_3NH_2	trace
Other soluble impurities, w/o	<0.2

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CURVE FIT FROM -46 TO +47.3 C WITH EQUATION:

$$C_p \text{ (cal/gm-c)} = 0.708 + 3.807 \times 10^{-4} t_{(c)} + 2.110 \times 10^{-6} t_{(c)}^2$$
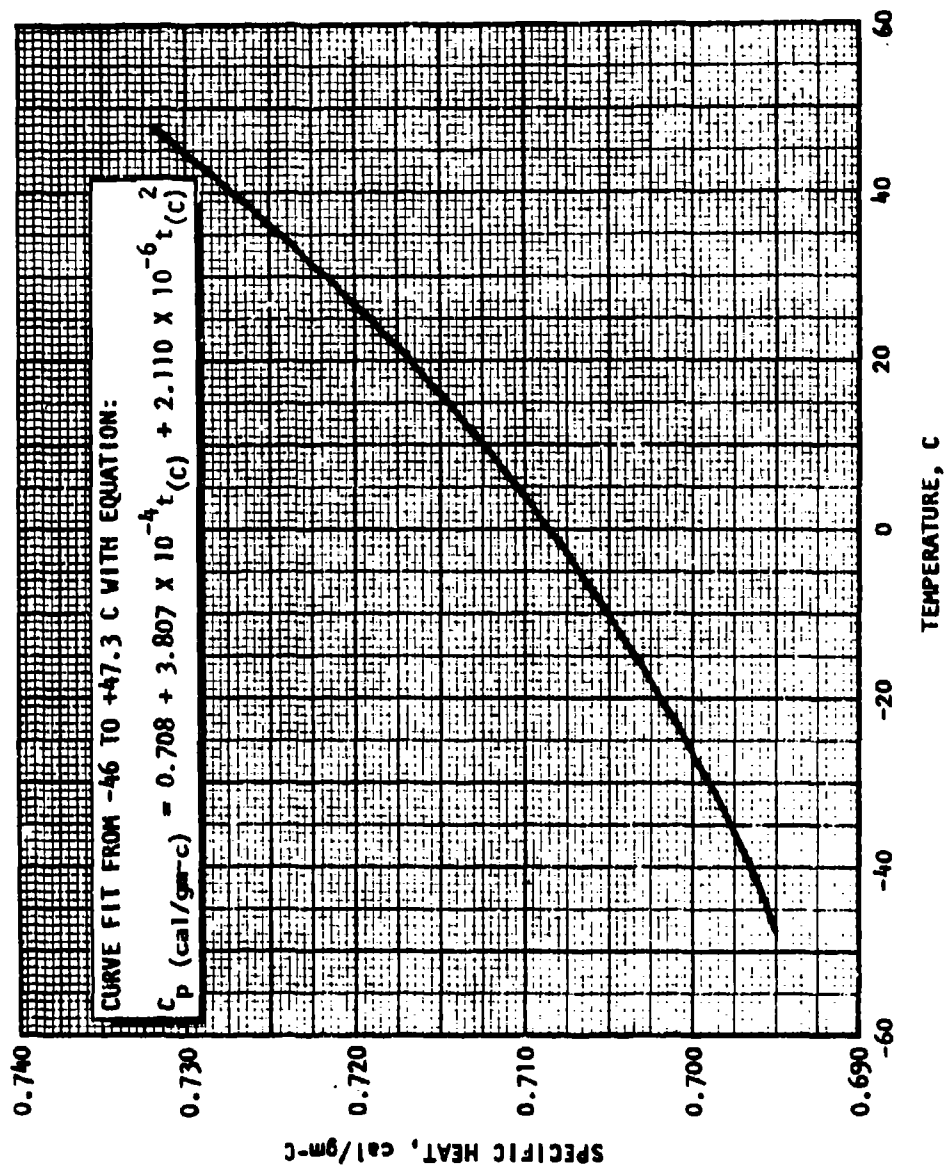
Figure 8. Specific Heat of MHF-3

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(C) Prior to conducting MHF-3 specific heat measurements above room temperature, thermal stability tests were initiated to ensure that vaporization of the liquid sample, and/or its potential decomposition products (as indicated by a pressure buildup) at the higher temperatures would not introduce significant errors in the measurements. A gas evolution apparatus was fabricated. The apparatus consisted of a copper sample container joined by means of a Kovar-to-Pyrex seal to a Hg-filled glass manometer in line with another manometer opened to ambient pressure. Using an ullage comparable to that maintained in the specific heat sample container at 45 C (113 F), gas evolution tests were conducted with MHF-3 at that temperature. The resulting average pressure buildup of ~0.3 mm Hg/hr indicated a rate which was tolerable during the period required for the specific heat measurements.

(C) Specific Heat of MHF-5. Measurements of specific heat of the MHF-5 fuel blend (nominal composition of 55 w/o $CH_3N_2H_3$-26 w/o N_2H_4-19 w/o $N_2H_4 \cdot HNO_3$) were successfully completed on the liquid phase over the temperature range of -47.4 to 7.5 C (-53.3 to 45.5 F). The sample container, which was fabricated and calibrated for use with MHF-3 (Ref. 3), was used also in the MHF-5 measurements. Because of the potential thermal sensitivity of MHF-5, the silver solder brazing normally used to cap (to ensure a complete seal) the sample container filling tube was replaced with indium metal, which has a lower melting point (~310 F). The sample container was loaded with 64.02 grams of MHF-5 under dry nitrogen in a glove bag.

(C) The experimental specific heat data and the results of chemical analysis of the MHF-5 sample are listed in Table 6. These data have been correlated with higher-temperature data (Ref. 7) and curve fit over a temperature range of -47.4 to 68.0 C (-53.3 to 154.4 F). The resulting equations:

$$C_{p(cal/gm-C)} = 0.664 + 1.21 \times 10^{-4} t_{(C)}$$

and

$$C_{p(Btu/lb-F)} = 0.662 + 6.74 \times 10^{-5} t_{(F)}$$

TABLE 6

EXPERIMENTAL SPECIFIC HEAT OF MHF-5
FUEL BLEND*

Temperature		Specific Heat
C	F	cal/gm-C
-47.38	-53.28	0.666
-45.24	-49.43	0.657
-38.64	-37.55	0.656
-36.62	-33.92	0.662
-36.52	-33.74	0.663
-29.84	-21.71	0.661
-27.72	-17.90	0.659
-20.66	-5.19	0.665
-13.31	8.04	0.667
-11.21	11.82	0.659
-4.50	23.90	0.663
-2.38	27.72	0.667
5.39	41.70	0.662
7.51	45.52	0.671

*Sample Composition:

$CH_3N_2H_3$, w/o	54.9
N_2H_4, w/o	25.4
$N_2H_4 \cdot HNO_3$, w/o	18.9
NH_3, w/o	0.2
H_2O, w/o	0.6

indicate a standard deviation of 0.005 cal/gm-C (Btu/lb-F). A graphical representation of the data in metric units is presented in Fig. 9.

(U) Although the data obtained at Rocketdyne resulted in a curve fit value at 7 C (44.6 F) which is 1.3 percent greater than a corresponding value from a previously reported (Ref. 8) curve fit, the analytical correlation of both sets of actual experimental data indicates good agreement of all of the data with the above equations.

(C) Prior to specific heat measurements on MHF-5, gas evolution tests were conducted to characterize any potential pressure buildup problems. The gas evolution apparatus used previously with MHF-3 was reassembled, leak checked, and loaded with MHF-5 for tests at ambient temperatures. Using an ullage of half that maintained in the specific heat sample container at ambient temperatures, the gas evolution test resulted in an average pressure buildup of ~1.8 mm Hg/hr. For the period of time involved in calorimetric measurements, this rate would not produce significant errors in the determinations.

Thermal Conductivity Measurements

(U) Thermal conductivity measurements of liquid propellants have been conducted through the use of a steady-state, concentric-cylinder conductivity cell described previously in Ref. 1 and 2. With this apparatus, the test liquid is contained in a very thin, annular passage between two aluminum alloy cylinders. An electrical resistance heater, located at the center of the inner cylinder, supplies the heat energy to establish a temperature gradient across the liquid layer. Copper constantan thermocouples, embedded in the cylinders close to the surfaces of the test fluid cavity, are used to measure the temperature gradient. A regulated d-c power supply is employed for the cell heater power.

(U) In evaluation of the applicability of this apparatus to measurements involving selected oxidizers, preliminary analysis indicates that replacement
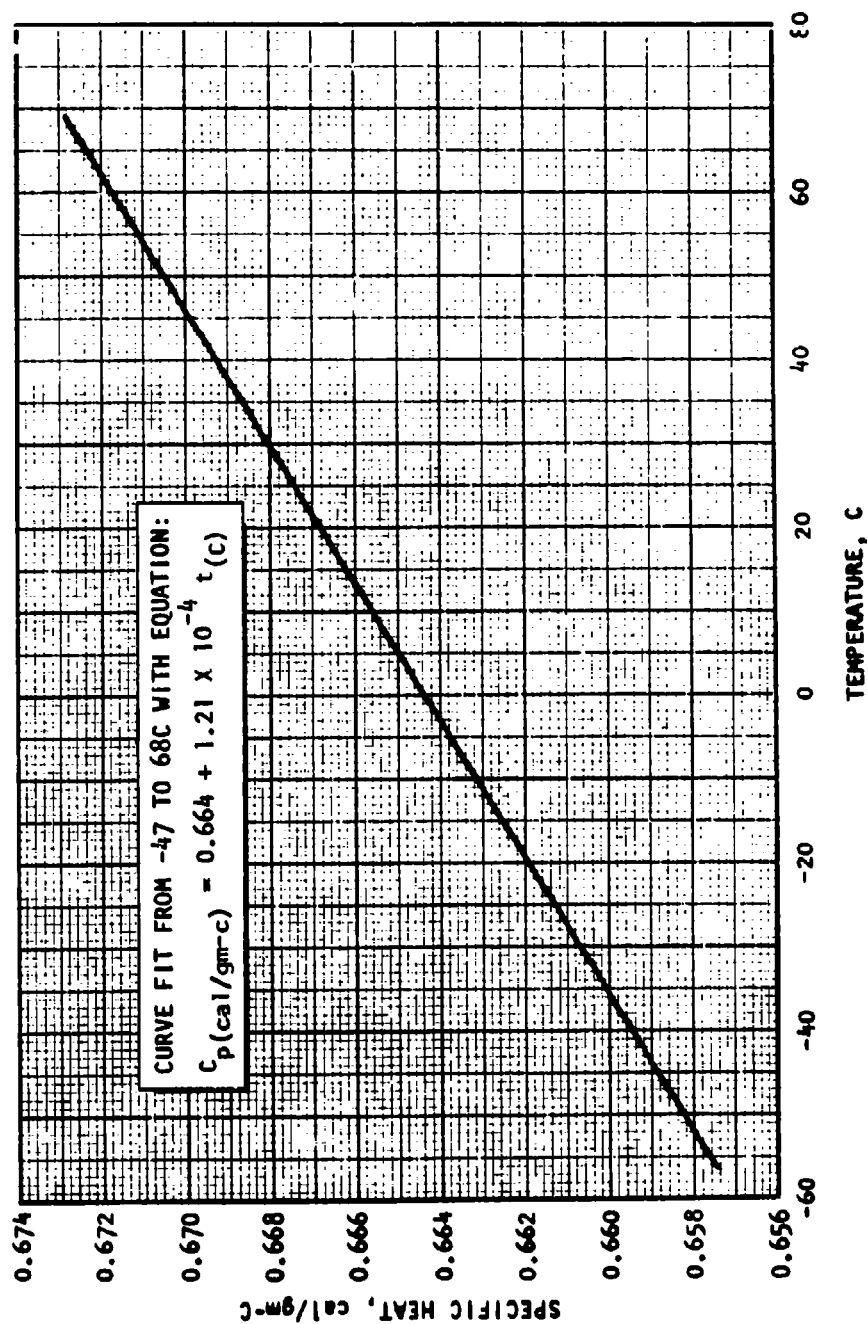
CURVE FIT FROM -47 TO 68C WITH EQUATION:

$$c_p \text{(cal/gm-c)} = 0.664 + 1.21 \times 10^{-4} \, t_{(C)}$$

Figure 9. Specific Heat of MHF-5

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and/or redesign of the cell sealing surfaces may be required. In addition, other techniques (notably those involving transient measurement procedures) are being evaluated under in-house funding to provide an alternate technique if the present apparatus is not suitable. If the present apparatus is considered applicable to oxidizer measurements, the apparatus will be completely disassembled and cleaned to remove all traces of residual fuel.

(U) The selection of ClF_5 as the initial oxidizer of interest for experimental thermal conductivity characterization has been approved by the Air Force Project Officer.

Viscosity Measurements

(U) Viscosity measurements on liquid propellants are being conducted with a stainless-steel capillary viscometer which has been described in Ref. 2. Kinematic viscosity is obtained by timing the decay of a small liquid head in flow through the capillary tubing. The movement of a liquid is followed by means of a differential transformer which determines the position of a magnetic float (indicating the liquid level) within a reservoir in the viscometer. For streamline flow in the capillary, the apparatus requires a single calibration constant which is obtained from tests with distilled water at various temperature levels.

(U) Viscosity of Chlorine Pentafluoride. Previously in this program (Ref. 3), ClF_5 viscosity measurements had been conducted at five temperature vels from 75 to 176 F at or near the corresponding ClF_5 vapor pressure. During this quarter, viscosity measurements on ClF_5 were continued to provide high-temperature data and investigate the possible effect of pressurization on viscosity. The results from these measurements, which were conducted at 202 ±1 F (94.4 ±0.6 C) over a total pressure range of 360 to 910 psia, are shown in Table 7. These total pressures were obtained through the use of gaseous nitrogen in the system ullage. The pressurizing gas was introduced shortly before each run to avoid solution equilibrium with the propellant.

TABLE 7

EXPERIMENTAL CHLORINE PENTAFLUORIDE VISCOSITY DATA*

Total Pressure, psia	Kinematic Viscosity, centistokes
360	0.114
380	0.116
570	0.114
720	0.114
770	0.112
810	0.114
860	0.110
910	0.118

*Measurements conducted at 202 ±1 F;
ClF_5 vapor pressure is 332 psia.

(U) These results indicate that in the range of 360 to 910 psia, pressure has no effect on the kinematic viscosity of ClF_5. Deviations shown in these measurements (notably at the two highest pressures) are considered to be spurious experimental effects. The source of these deviations, and their possible relation to high-pressure operation, is not presently known. In previous measurements on the saturated liquid (at temperatures up to 176 F), the viscometer has performed with a precision on the order of ±1 percent.

(U) The kinematic viscosity of ClF_5 at 202 F is 0.114 centistokes for the saturated and compressed liquid below 1000 psia. For the saturated liquid, using a ClF_5 density established in Ref. 6, the corresponding absolute or dynamic viscosity is 0.168 centipoises. This value has been incorporated in Fig. 10, which illustrates previously available ClF_5 viscosity data.
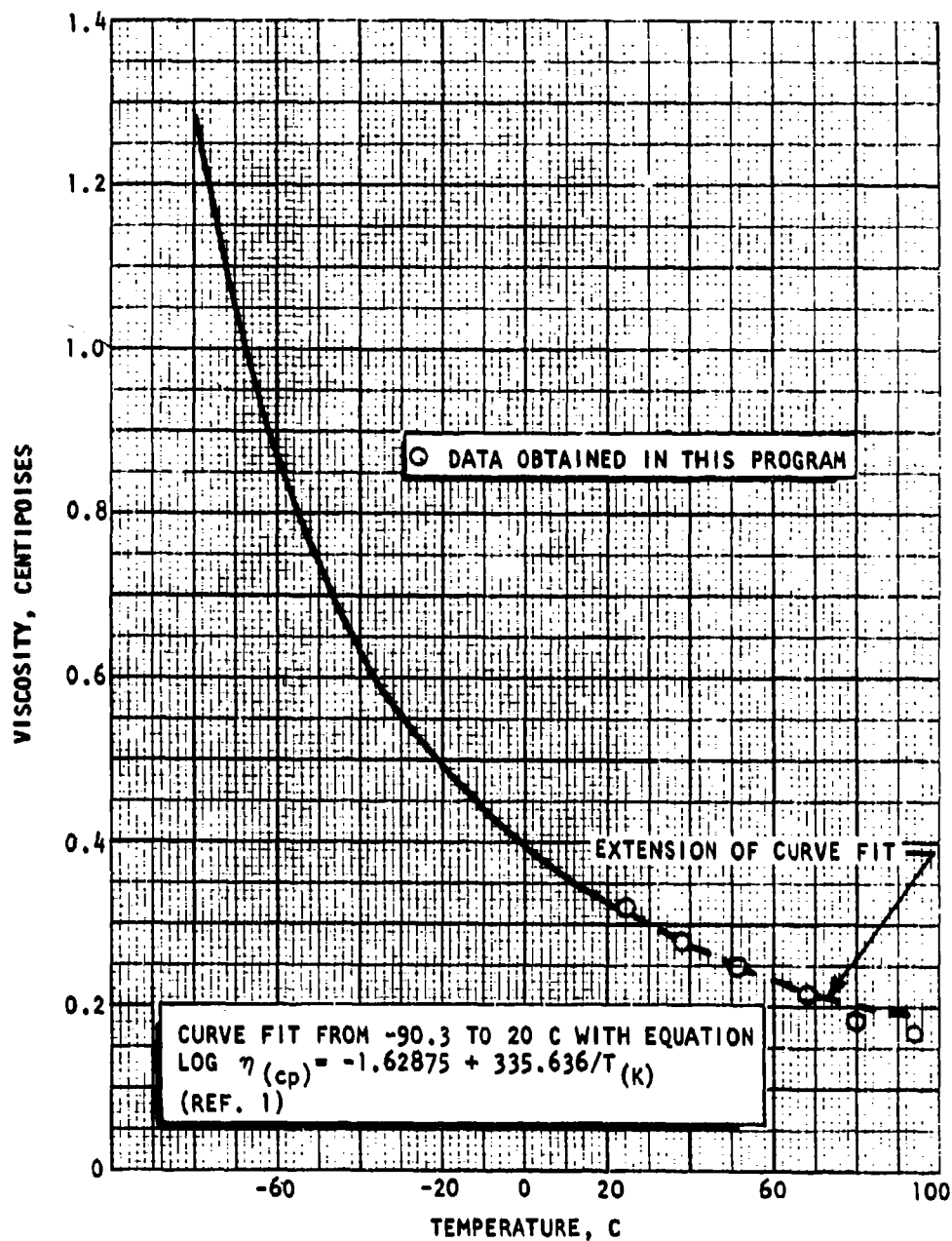
Figure 10. Viscosity of Saturated Liquid
Chlorine Pentafluoride

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(U) The invariance of kinematic viscosity with relatively minor compression of the liquid is in accordance with general theoretical and empirical correlations. The absolute viscosity of the compressed liquid must be somewhat larger than that at saturation and it is a function of the isothermal compressibility of the liquid (which is not known for ClF_5 at 200 F). Even at this high temperature (relative to the critical point) and correspondingly large compressibility, the pressure effects are not significant unless very high pressures are attained. From the data in Ref. 2, the adiabatic compressibility of ClF_5 at 202 F is estimated at about 4×10^{-5} psi^{-1} (with the isothermal compressibility being typically larger by 10 to 50 percent). Hence, the density increase and corresponding absolute viscosity increase within 1000 psia should be in the order of 3 percent.

PHASE III: EVALUATION AND COMPILATION OF DATA

OBJECTIVE

(U) During the entire period of the contractual program, efforts under Phase III are directed toward the assembly of all data generated by Phases I and II, verification of all the data sources, critical comparison of conflicting data, and tabulation of the results. The final selection of the best values will be summarized in an annual technical report.

RESULTS AND ACCOMPLISHMENTS

(U) In the current report period, Phase III effort has been directed primarily at the compilation and evaluation of physical properties of various selected propellants from the references located in the Phase I literature survey. The remaining effort has been concentrated on the reduction, evaluation, and correlation of all data generated as a result of the Phase II experimental efforts; however, to maintain continuity in this text, these results are reported under pertinent Phase II headings.

Surface Tension of Propellants

(U) At the request of the Air Force Project Engineer, all previously published surface tension data on ClF_3, ClF_5, N_2O_4, 50 N_2H_4-50 UDMH, N_2H_4, MMH, UDMH, MHF-3, and MHF-5 have been compiled and evaluated. These data are summarized in the following paragraphs.

(U) __Chlorine Trifluoride__. The surface tension of saturated liquid ClF_3 has been experimentally determined (Ref. 9) by the method of capillary rise over the temperature range of 0 to 50 C (32 to 122 F). A curve fit of the data, shown in Fig. 11, can be expressed by the following equations:

$$\gamma_{(dynes/cm)} = 26.7 - 0.16\ t_{(C)}$$

and

$$\gamma_{(lb/ft)} = 2.05 \times 10^{-3} - 6.10 \times 10^{-6} \, t_{(F)}$$

(U) <u>Chlorine Pentafluoride</u>. The surface tension of ClF_5, which was experimentally determined (Ref. 6) over a temperature range of -50 to 25 C (-58 to 77 F), is shown in Fig. 12. The equations representing these data are:

$$\gamma_{(dynes/cm)} = 57.949 - 0.1446 \, T_{(K)}$$

and

$$\gamma_{(lb/ft)} = 3.9708 \times 10^{-3} - 0.5506 \times 10^{-5} \, T_{(R)}$$

(U) <u>Nitrogen Tetroxide</u>. The surface tension of liquid N_2O_4 was experimentally determined to be 27.0 dynes/cm (1.850×10^{-3} lb/ft) at 20 C (68 F) with a duNouy tensiometer (Ref. 10). This comparatively recent data point conflicts with previously reported data (Ref. 11); however, this value represents the propellant-grade N_2O_4 presently in use.

(U) <u>50 w/o N_2H_4-50 w/o UDMH</u>. A duNouy tensiometer was also used to measure (Ref. 10) the surface tension of the 50 w/o N_2H_4-50 w/o UDMH fuel blend at 20C (68 F). A value of 30.3 dynes/cm (2.076×10^{-3} lb/ft) was reported from this measurement.

(U) <u>Hydrazine</u>. Although surface tension values of 66.67 dynes/cm at 25 C and 62.32 dynes/cm at 35 C had been previously reported for anhydrous N_2H_4 in Ref. 12 and 13, respectively, the later work of Ref. 14 was used to curve fit the data shown in Fig. 13. The equations obtained from the curve fit are as follows:
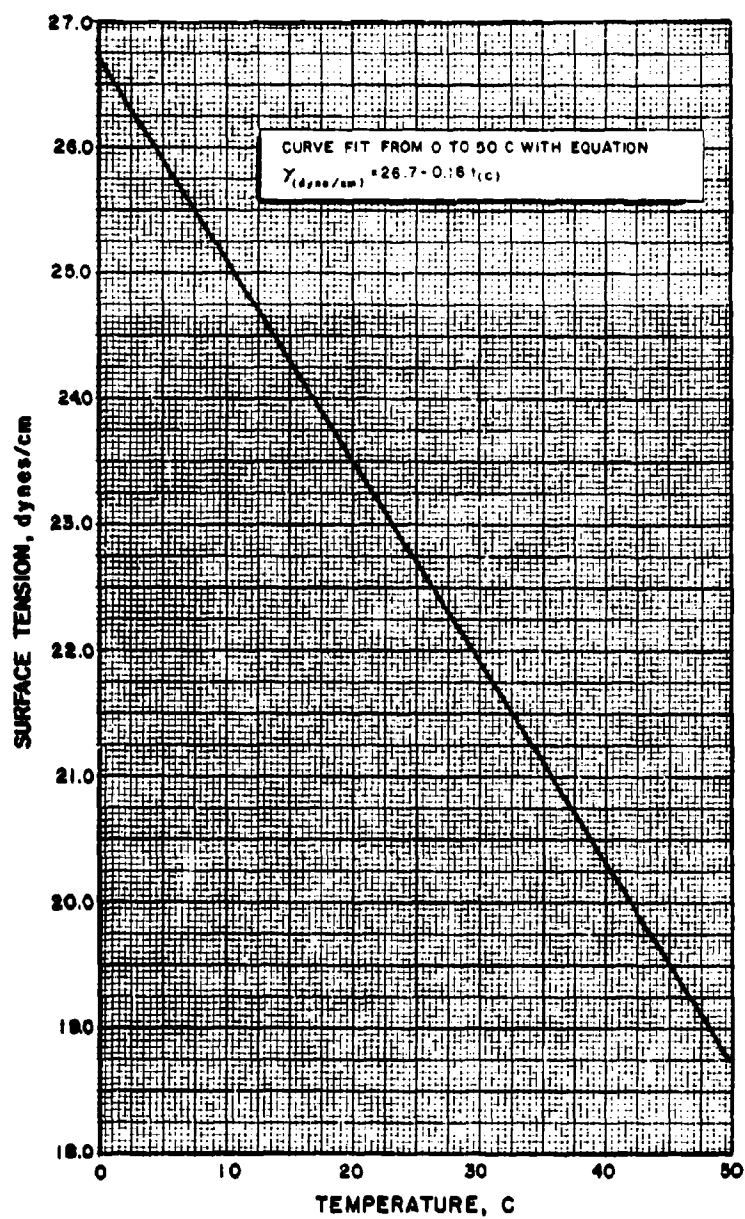
$$\gamma_{(dynes/cm)} = 72.46 - 0.242 \, t_{(C)}$$

CURVE FIT FROM 0 TO 50 C WITH EQUATION

$$\gamma_{(dyne/cm)} = 26.7 - 0.16 \, t_{(C)}$$

Figure 11. Surface Tension of Saturated Liquid Chlorine Trifluoride

45

CURVE FITTED FROM -50 TO 25 C WITH EQUATION
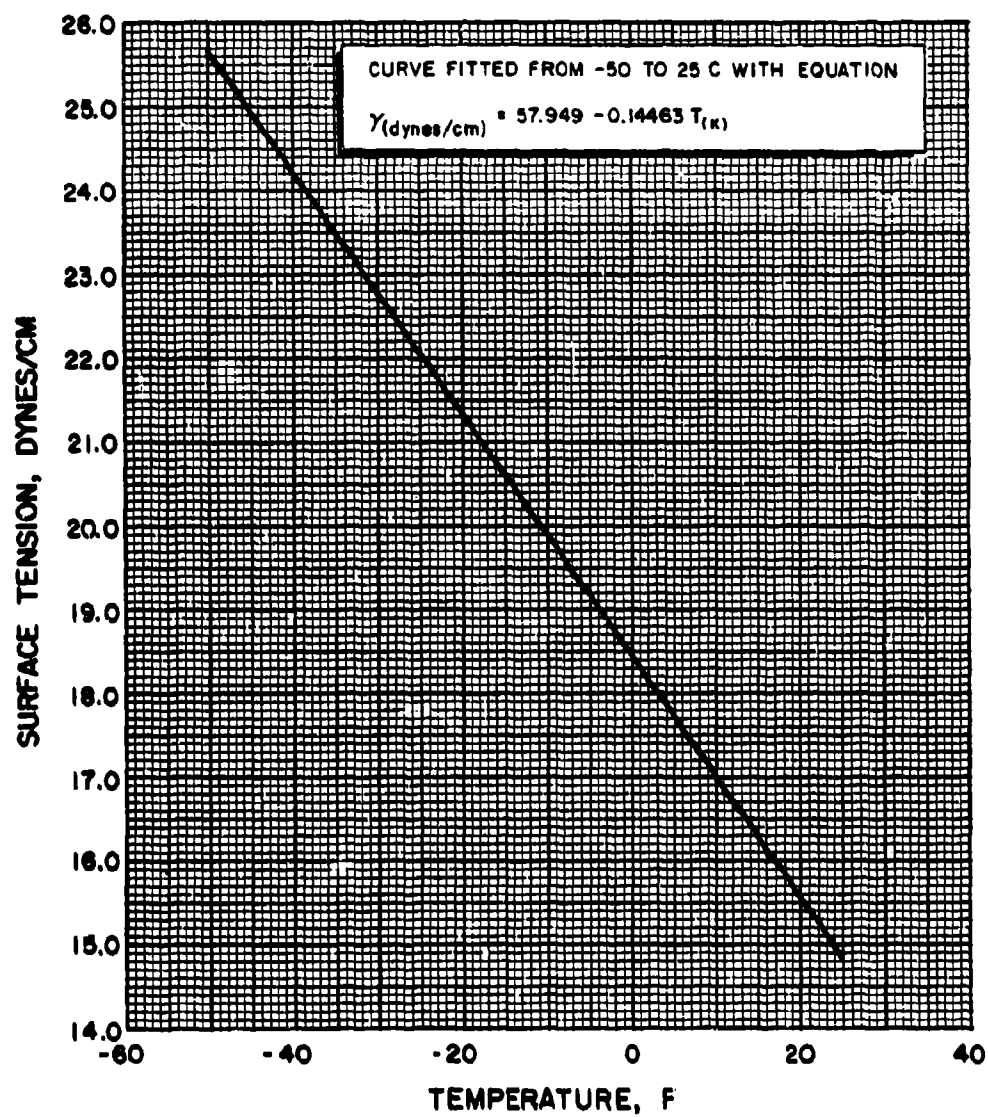
$\gamma_{(dynes/cm)} = 57.949 - 0.14463 \, T_{(K)}$

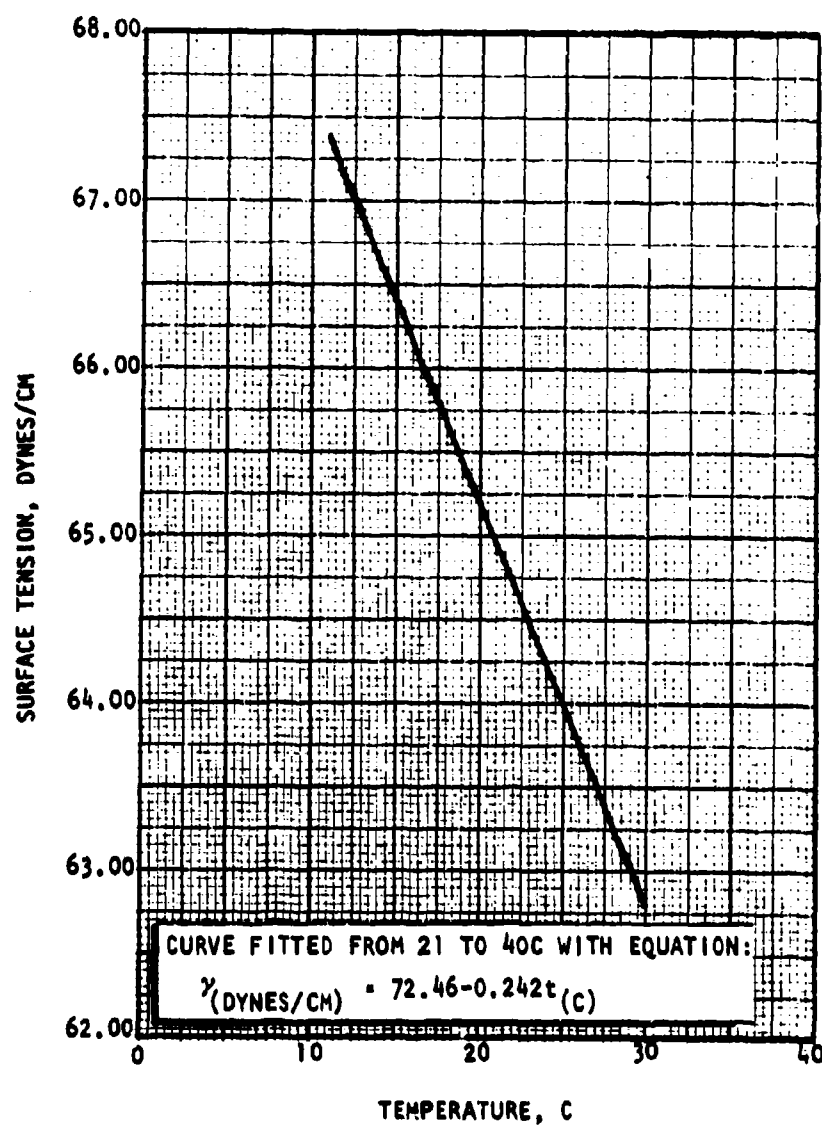Figure 12. Surface Tension of Saturated Liquid Chlorine
Pentafluoride (Ref. 6)

Figure 13. Surfacc Tension of Anhydrous Hydrazine (Ref. 14).

and

$$\gamma_{(lb/ft)} = 5.261 \times 10^{-3} - 9.25 \times 10^{-6} \, t_{(F)}$$

(U) <u>Monomethylhydrazine</u>. The surface tension of $CH_3N_2H_3$ (MMH) was measured by the capillary rise method over the temperature range of -40 to 60 C (-40 to 140 F) in Ref. 15. These data (Fig. 14) were curve fit with the following equations:

$$\gamma_{(dynes/cm)} = 36.29 - 0.0987 \, t_{(C)}$$

and

$$\gamma_{(lb/ft)} = 2.607 \times 10^{-3} - 3.76 \times 10^{-6} \, t_{(F)}$$

(U) <u>Unsymmetrical Dimethylhydrazine</u>. The surface tension of $(CH_3)_2N_2H_2$ (UDMH) was also measured by the capillary rise method over the temperature range of -54 to 50 C (-65.2 to 122 F) in Ref. 15. These data (Fig. 15) can be represented with the following equations:

$$\gamma_{(dynes/cm)} = 26.53 - 0.108 \, t_{(C)} + 2.08 \times 10^{-4} \, t_{(C)}^2$$

and

$$\gamma_{(lb/ft)} = 1.954 \times 10^{-3} - 4.399 \times 10^{-6} \, t_{(F)} + 4.390 \times 10^{-9} \, t_{(F)}^2$$

A value of 24.4 dynes/cm (1.612×10^{-3} lb/ft) at 20 C (68 F), reported in Ref. 10, is in good agreement with these data.

(C) <u>MHF-3 Fuel Blend</u>. No data have been reported on the surface tension of the MHF-3 fuel blend (nominal composition of 86 w/o MMH-14 w/o N_2H_4).

(C) <u>MHF-5 Fuel Blend</u>. No experimental surface tension data have been reported for the MHF-5 fuel blend (nominal composition of 55 w/o MMH-26 w/o N_2H_4-19 w/o $N_2H_5NO_3$).

SURFACE TENSION, DYNES/CM

68.00

67.00

66.00

65.00

64.00

63.00

CURVE FITTED FROM 21 TO 40C WITH EQUATION:

$\gamma_{(DYNES/CM)} = 72.46-0.242t_{(C)}$

62.00

0   10   20   30   40

TEMPERATURE, C

Figure 13. Surface Tension of Anhydrous Hydrazine (Ref. 14).

and

$$\gamma_{(lb/ft)} = 5.261 \times 10^{-3} - 9.25 \times 10^{-6} \; t_{(F)}$$

(U) <u>Monomethylhydrazine</u>. The surface tension of $CH_3N_2H_3$(MMH) was measured by the capillary rise method over the temperature range of -40 to 60 C (-40 to 140 F) in Ref. 15. These data (Fig. 14) were curve fit with the following equations:

$$\gamma_{(dynes/cm)} = 36.29 - 0.0987 \; t_{(C)}$$

and

$$\gamma_{(lb/ft)} = 2.607 \times 10^{-3} - 3.76 \times 10^{-6} \; t_{(F)}$$

(U) <u>Unsymmetrical Dimethylhydrazine</u>. The surface tension of $(CH_3)_2N_2H_2$ (UDMH) was also measured by the capillary rise method over the temperature range of -54 to 50 C (-65.2 to 122 F) in Ref. 15. These data (Fig. 15) can be represented with the following equations:

$$\gamma_{(dynes/cm)} = 26.53 - 0.108 \; t_{(C)} + 2.08 \times 10^{-4} \; t_{(C)}^{2}$$

and

$$\gamma_{(lb/ft)} = 1.954 \times 10^{-3} - 4.399 \times 10^{-6} \; t_{(F)} + 4.390 \times 10^{-9} \; t_{(F)}^{2}$$

A value of 24.4 dynes/cm (1.612×10^{-3} lb/ft) at 20 C (68 F), reported in Ref. 10, is in good agreement with these data.

(C) <u>MHF-3 Fuel Blend</u>. No data have been reported on the surface tension of the MHF-3 fuel blend (nominal composition of 86 w/o MMH-14 w/o N_2H_4).

(C) <u>MHF-5 Fuel Blend</u>. No experimental surface tension data have been reported for the MHF-5 fuel blend (nominal composition of 55 w/o MMH-26 w/o N_2H_4-19 w/o $N_2H_5NO_3$).
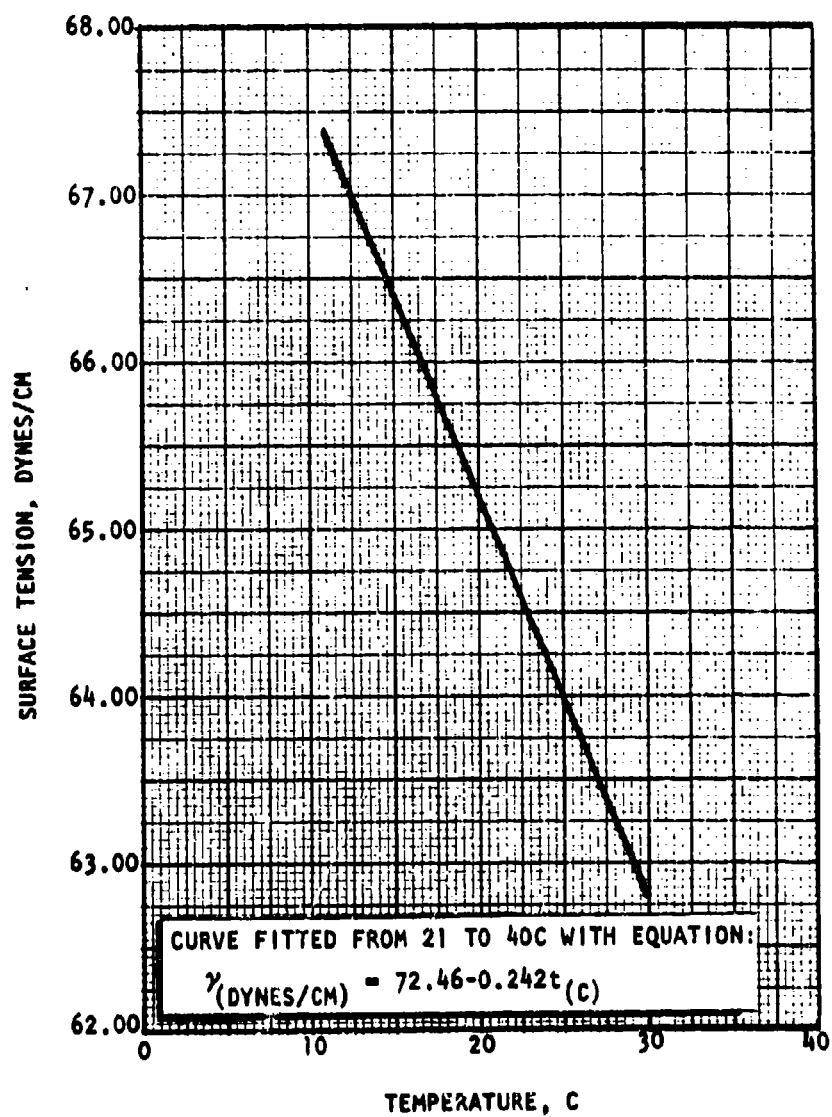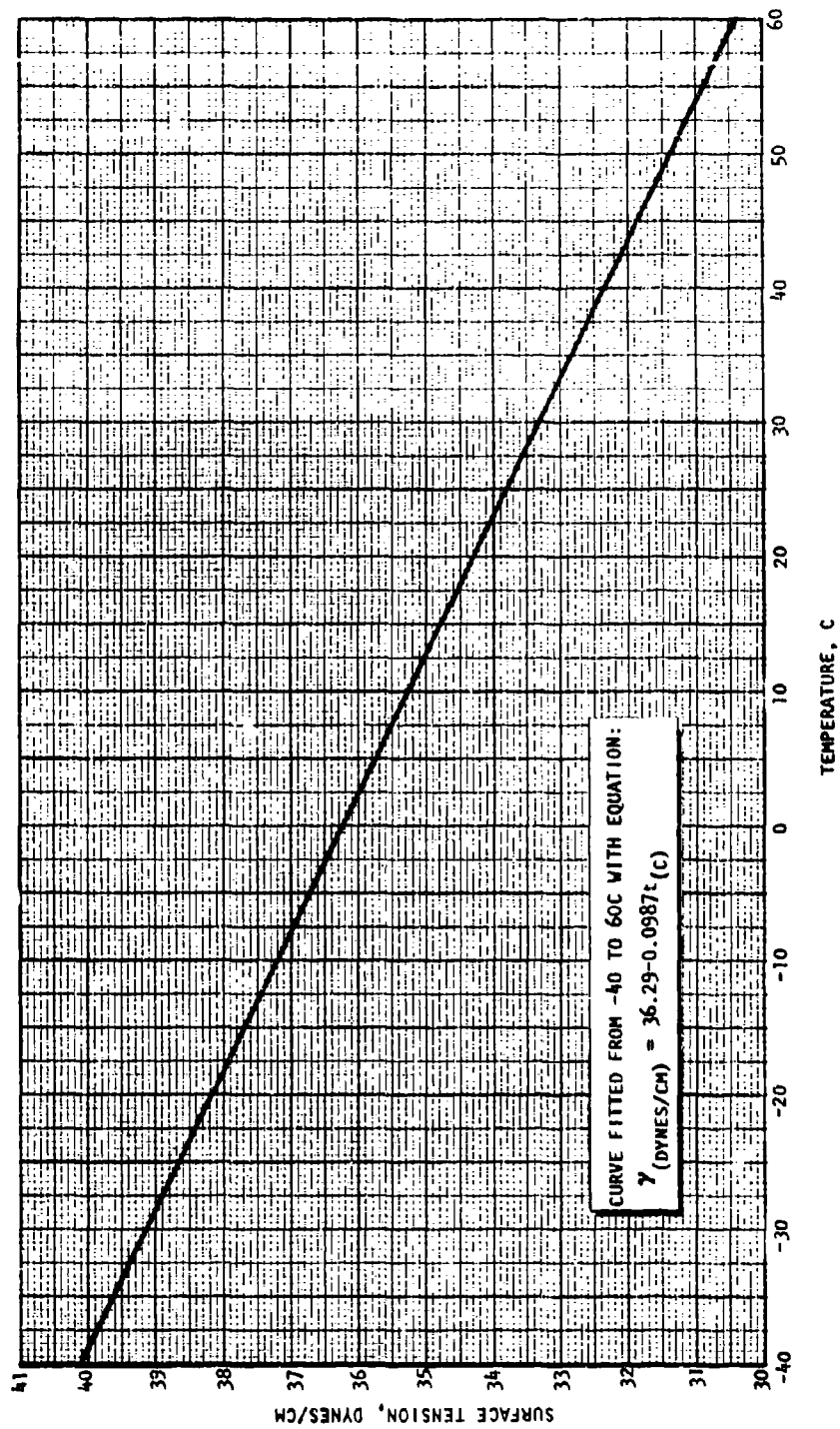
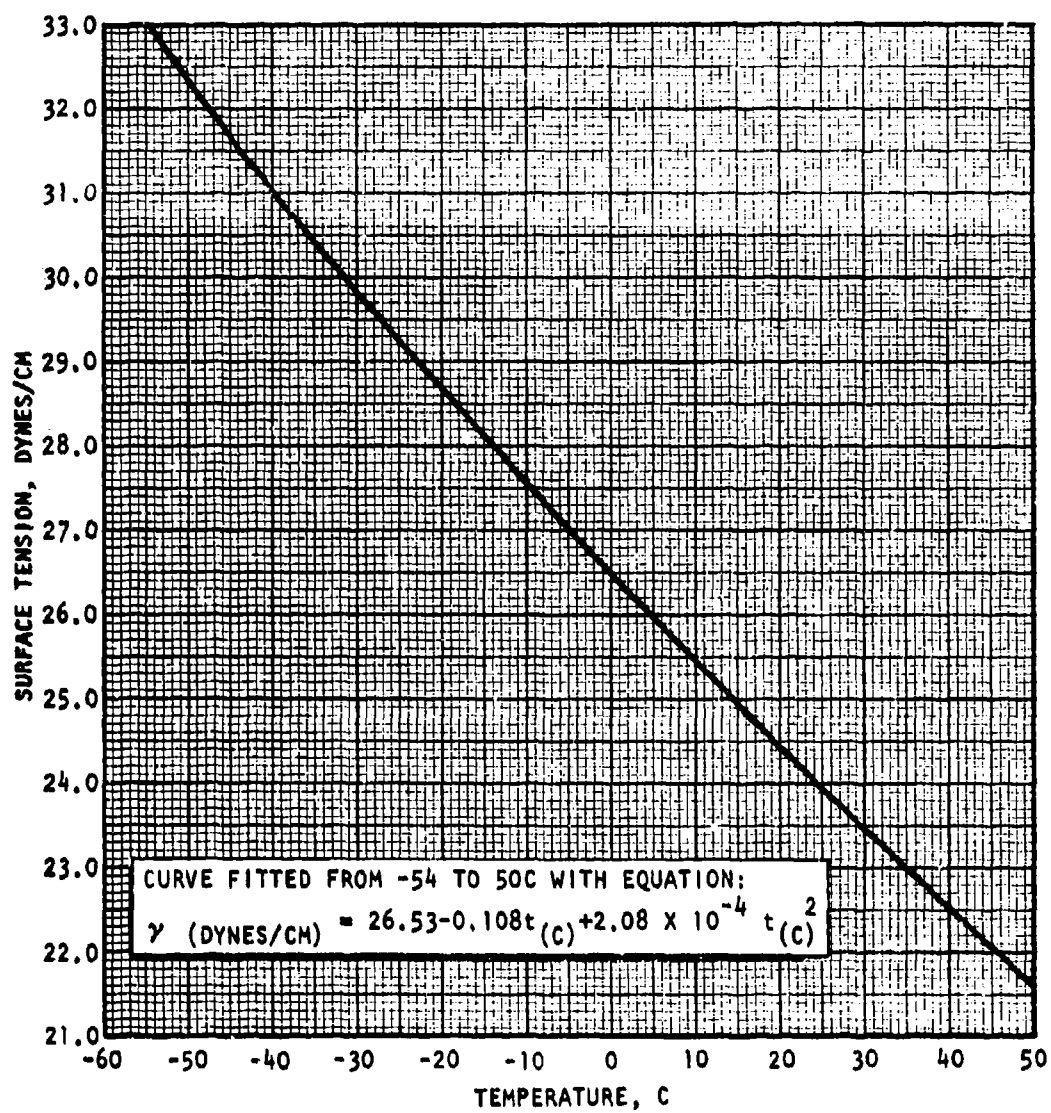Figure 14. Surface Tension of Monomethylhydrazine (Ref. 15)

Figure 15. Surface Tension of UDMH (Ref. 15)

50

(U) Nitrogen Tetroxide Physical Property Compilations

Preparation of a physical properties bibliography for N_2O_4 is continuing.
In addition, a complete evaluation of N_2O_4 physical properties data is
in progress.

(U) Nitrogen Tetroxide Density. As a part of the N_2O_4 physical property
compilations, the available experimental data on N_2O_4 density was compiled
and correlated. These correlated data were used in the calculation of the
adiabatic compressibility of liquid N_2O_4 from experimental sonic velocity
data (as noted in Phase II). From a literature survey, saturated liquid
N_2O_4 density data were obtained over the range -11.2 to 158.2 C (11.8 to
316.8 F). These data (Ref. 16 through 20) were correlated and curve fit
with a least-squares computer program from -11.2 to 93.3 C (11.8 to 199.9 F).
The following equations were obtained from this curve fit:

$$\rho_{(gm/cc)} = 1.490 - 2.124 \times 10^{-3} \, t_{(C)} - 5.01 \times 10^{-6} \, t_{(C)}^2$$

and

$$\rho_{(lb/cu \, ft)} = 95.31 - 6.749 \times 10^{-2} \, t_{(F)} - 9.66 \times 10^{-5} \, t_{(F)}^2$$

The available data above 93.3 C were omitted from the present correlation
to simplify the curve fit; however, this temperature range satisfied the
range of the available sonic velocity data.

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13. ABSTRACT

The results of the fifth quarter year's effort of a 24-month program on the analytical and experimental characterization of the physical properties of selected liquid propellants are presented in three phases. In Phase I, a continuous review of the literature was conducted to ensure the acquisition and documentation of the latest possible propellant properties data for evaluation and possible inclusion into a propellant properties handbook. Phase II experimental efforts have resulted in the measurement of chlorine trifluoride vapor pressure in the high-temperature region and an estimation of critical properties; sonic velocity in chlorine trifluoride and chlorine pentafluoride under pressurized conditions; nitrogen gas solubility in chlorine pentafluoride; specific heat of saturated liquid chlorine trifluoride; thermal conductivity of MHF-5; and viscosity of chlorine pentafluoride. Phase III efforts included the evaluation and assembly of all data generated in Phases I and II, a curve fit of specific heat data on solid chlorine trifluoride, and a report of unpublished data on the normal boiling point of chlorine pentafluoride and chlorine pentafluoride storability. (U)

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Chlorine Trifluoride						
Chlorine Pentafluoride						
Hydrazine						
Sonic Velocity						
Thermal Conductivity						
Specific Heat						